Hybrid Digital/Optical Computer Systems

Institution of Electrical Engineers – Seminar - Arundel

21st November 2000

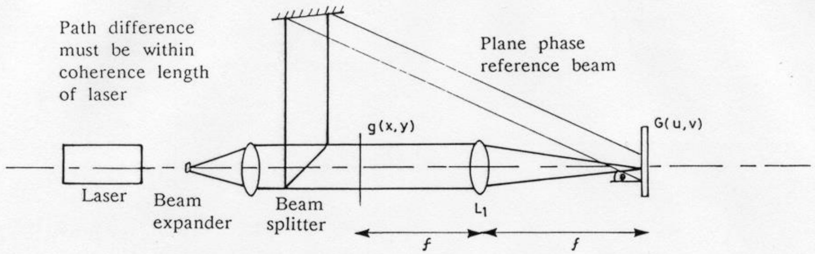
Professor Chris R. Chatwin – Hub Research Director

Dr Young, Dr Budgett, Dr Birch, Mr Claret-Tournier, Dr Sharp

School of Engineering & Information Technology

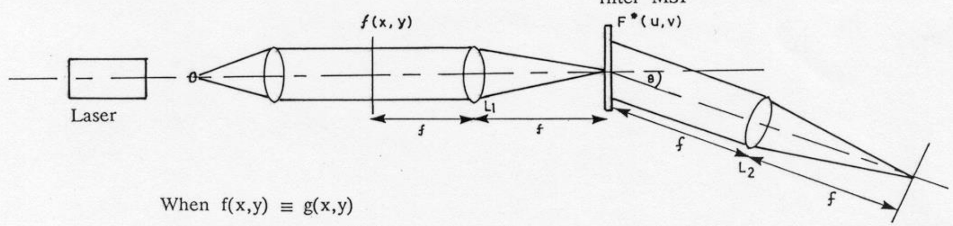
University of Sussex

Filter Recording and Playback



Spectrum of g(x,y) recorded holographically by placing on carrier of spatial frequency $\alpha = \frac{\sin\theta}{\lambda}$

CORRELATION WITH INPUT SCENE

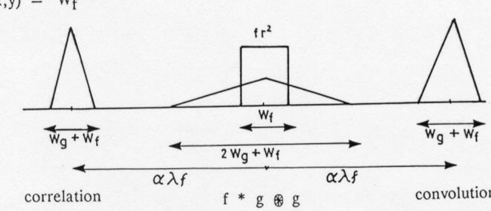


When $f(x,y) \equiv g(x,y)$

Autocorrelation —— Reference beam is reconstructed by MSF, focused by L_2 to an on−axis spot.

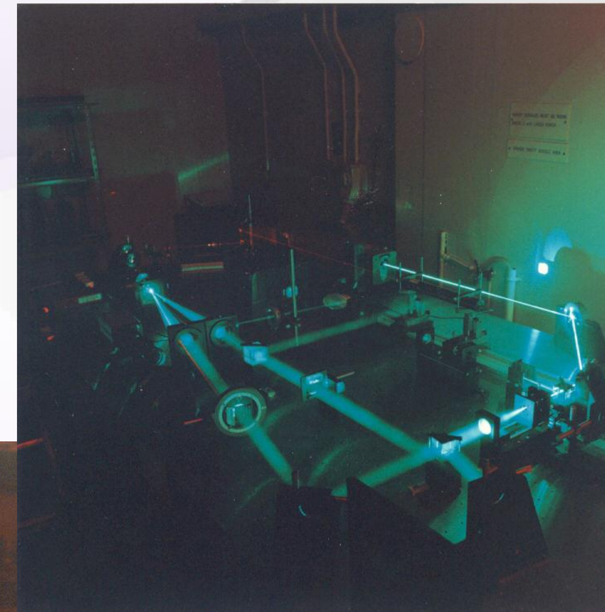
TOTAL OUTPUT PLANE

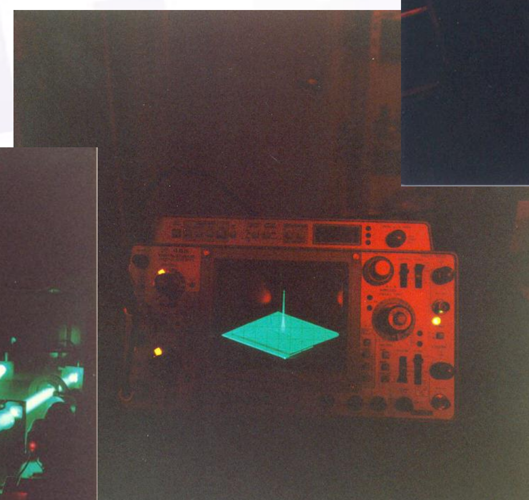
width of $g(x,y) = W_g$
width of $f(x,y) = W_f$



$\alpha\lambda f > \frac{3W_g}{2} + W_f$ implies high carrier frequency required if moderate focal length lenses to be used.

Joint Transform Correlator





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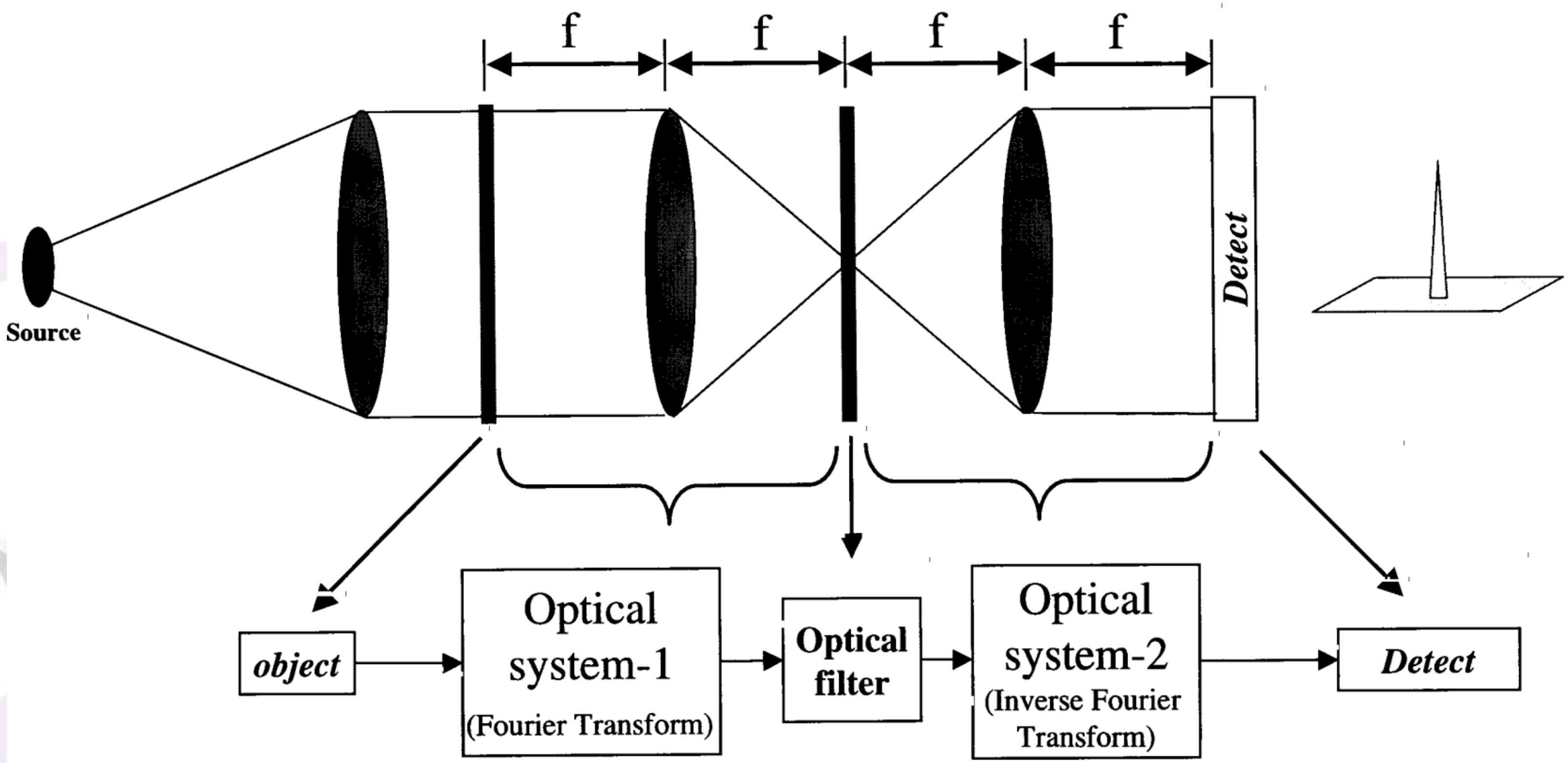
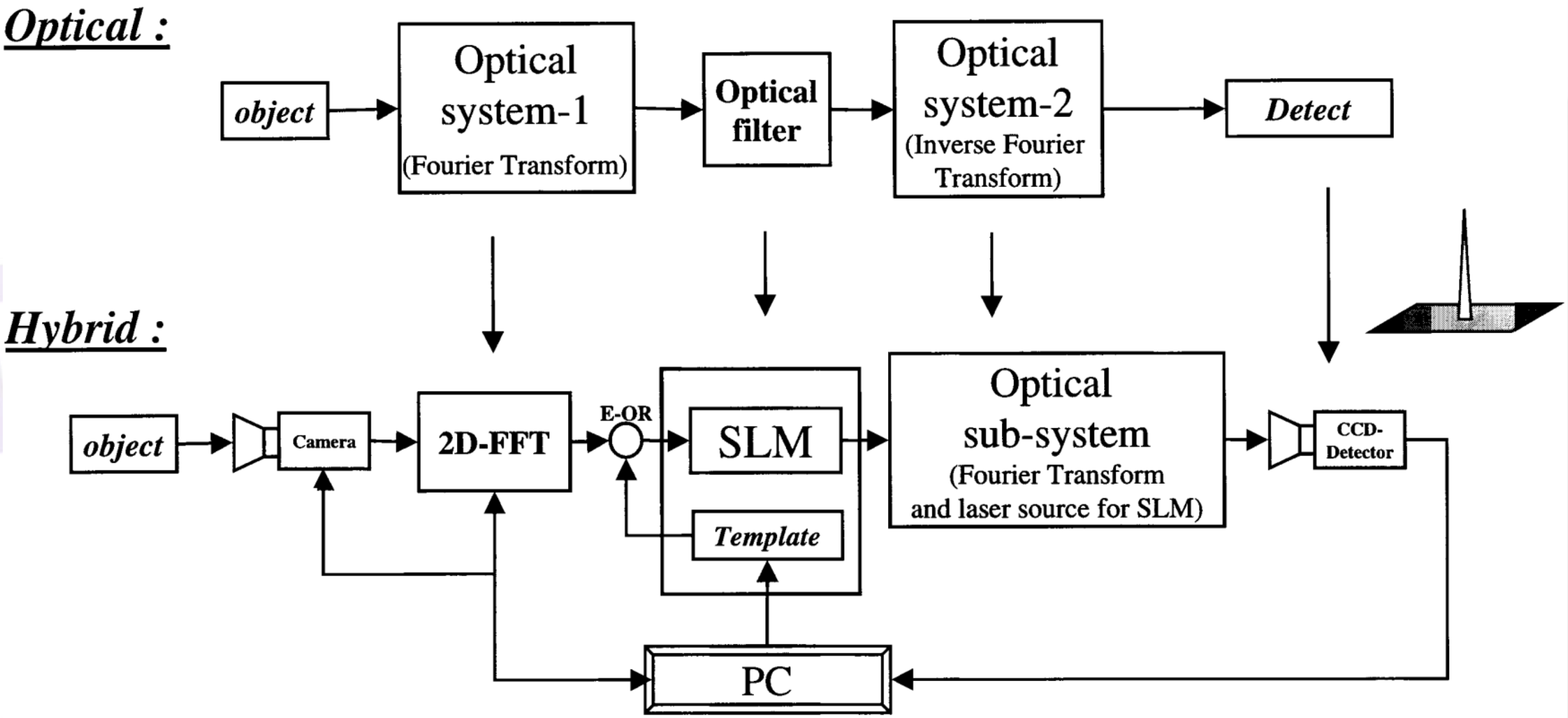
Conventional Optical Correlation



Hybrid Digital Optical Correlator



Hybrid System Aims

- Correlators offer high resolution image recognition but…
- Difficult to get data in and out at speed
- Input SLMs have low dynamic range
- Mechanical and thermal stability can be poor
- Large physical size
- Difficult to align
- f/# matching problems

Solution:

- Replace first Fourier transform with a digital FFT
- The data is mixed with template filters and placed on to an SLM which is then optically Fourier transformed
- We can search many filters in a video frame time

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Summary

- Two systems will be described:
  - One with an optical template memory addressed by an acousto optic scanner
  - One with a digital template memory, which is far more compact
- Both these systems have been built by the Laser and Photonic Systems Research Group: Dr Young, Dr Budgett, Dr Birch, Mr Claret-Tournier, Dr Sharp

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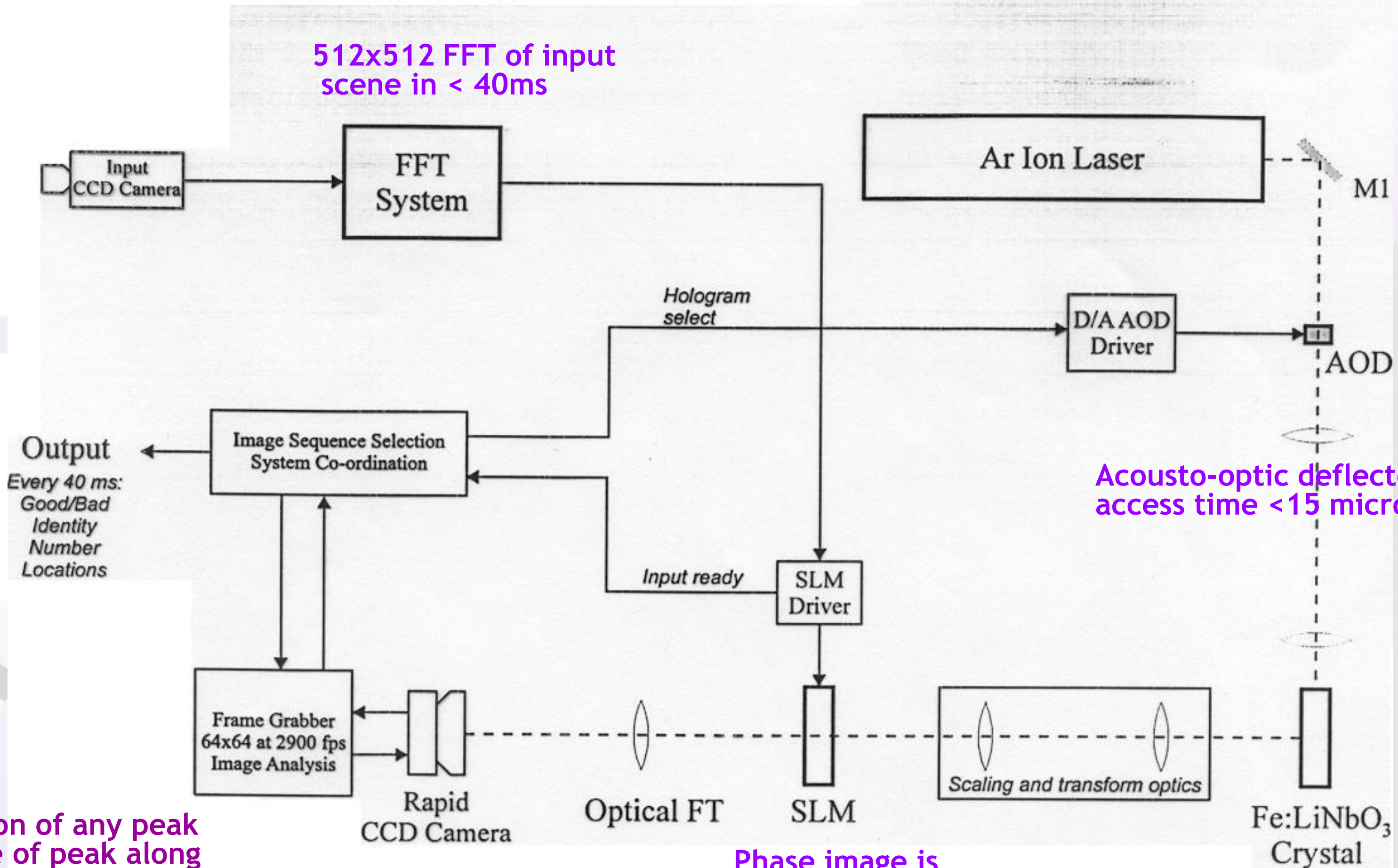
Schematic of Hybrid Optical/Digital Correlator Experimental Layout



512x512 FFT of input scene in < 40ms

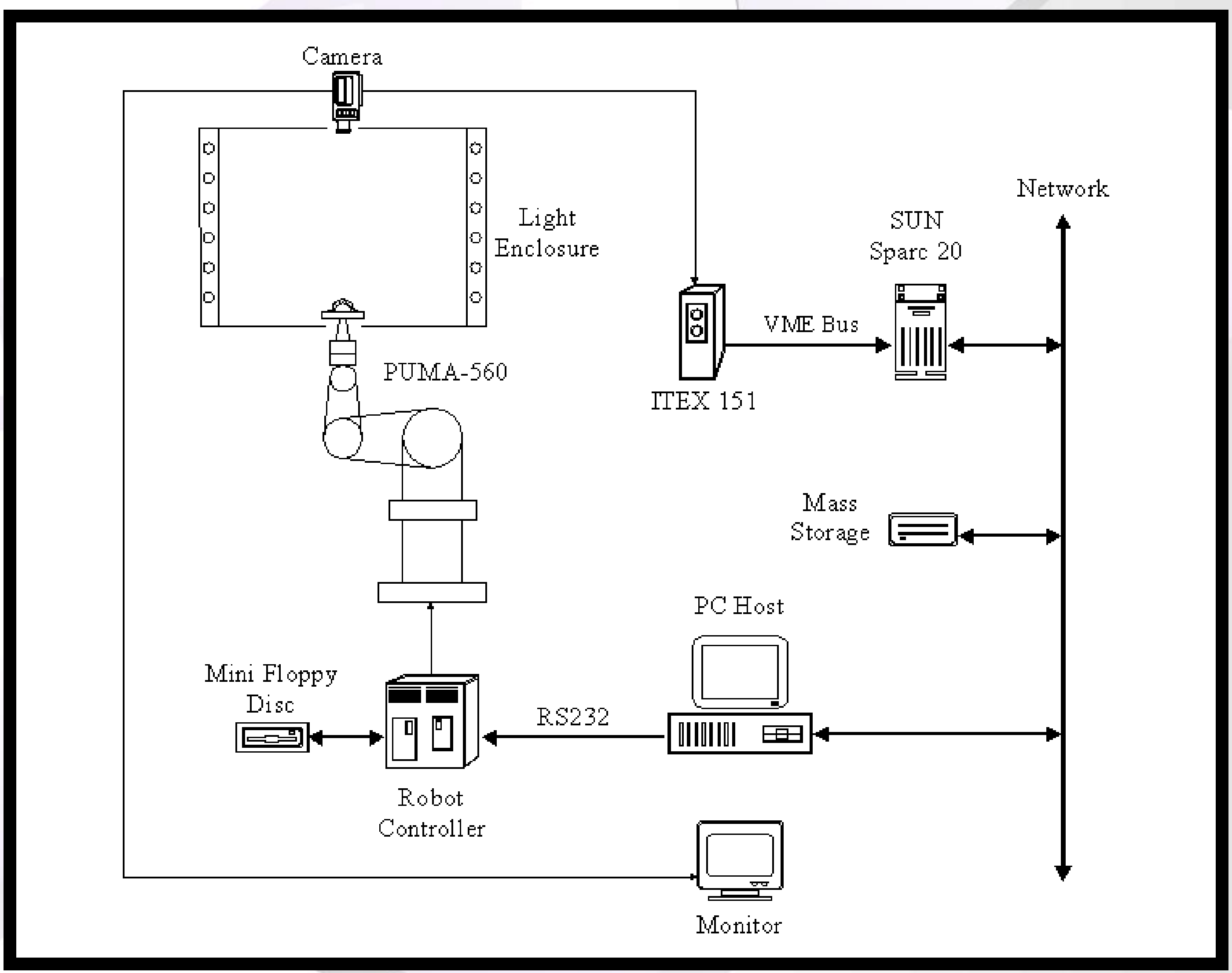
Acousto-optic deflector random access time <15 microseconds

X and Y position of any peak detected; Size of peak along X and Y axes; Density of correlation peak

Correlation of reconstructed “image” and SLM “image” produced by final lens

Phase image is displayed on the phase modulating SLM

High Speed Hybrid Correlator System : Image Acquisition



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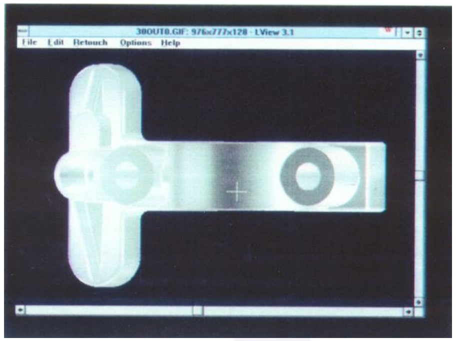
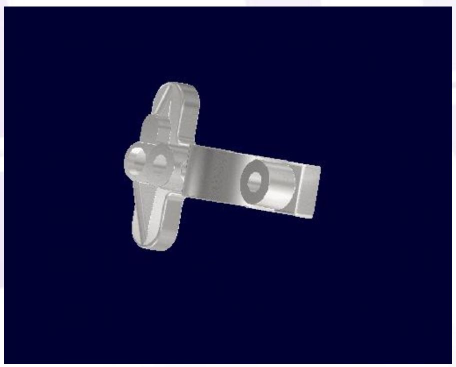
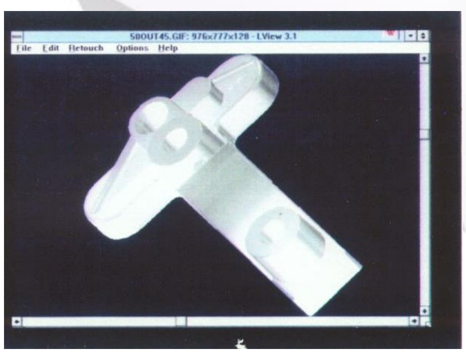
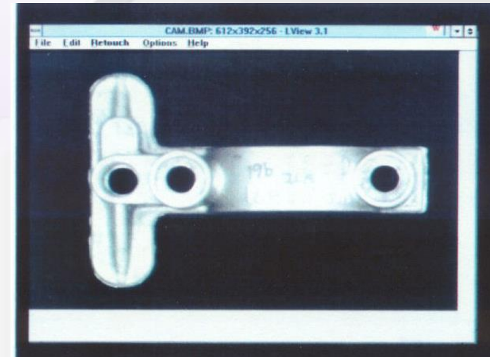
Catia Solid Models







Actual images some with clutter



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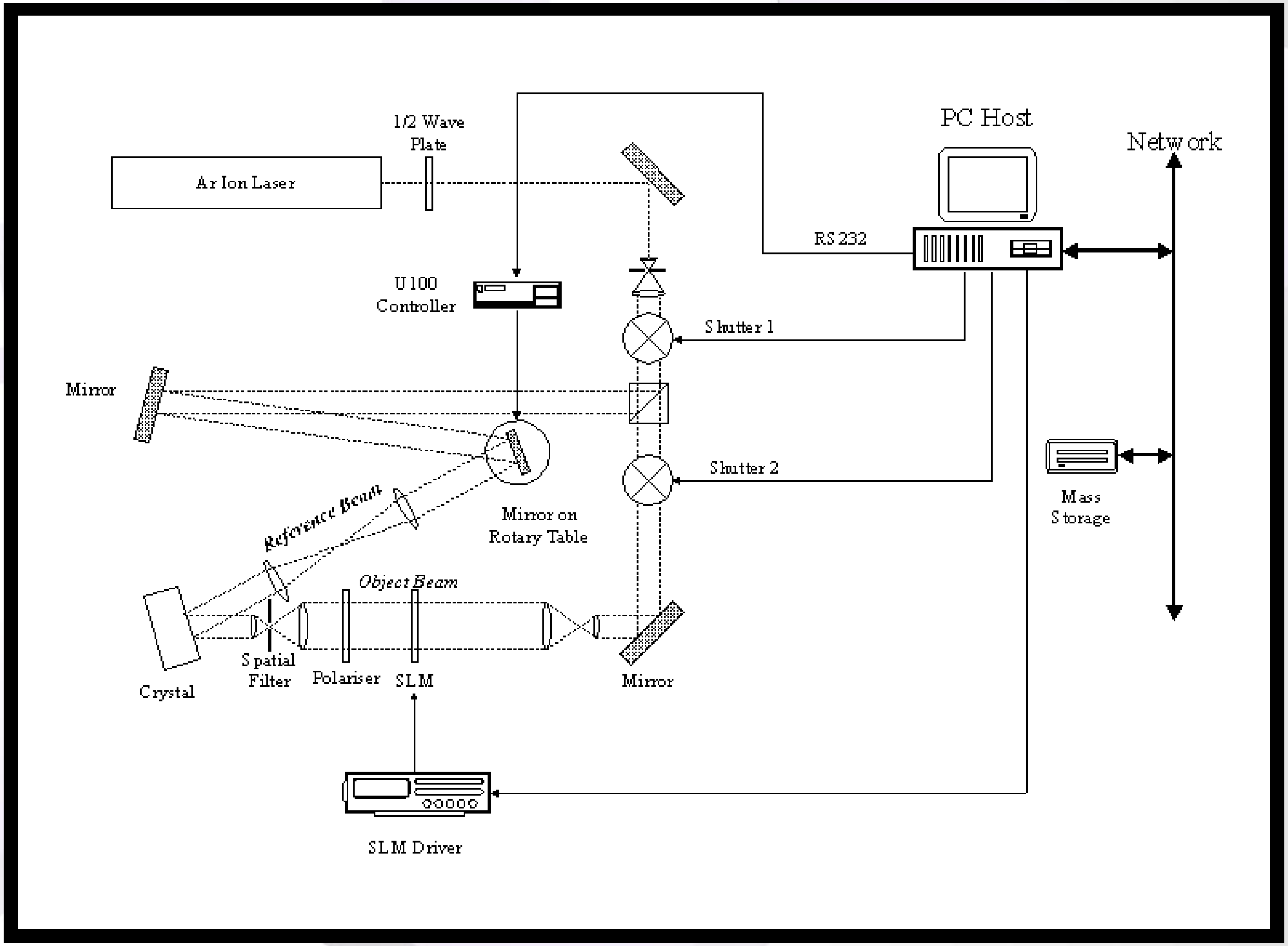
Volume Hologram Recording System



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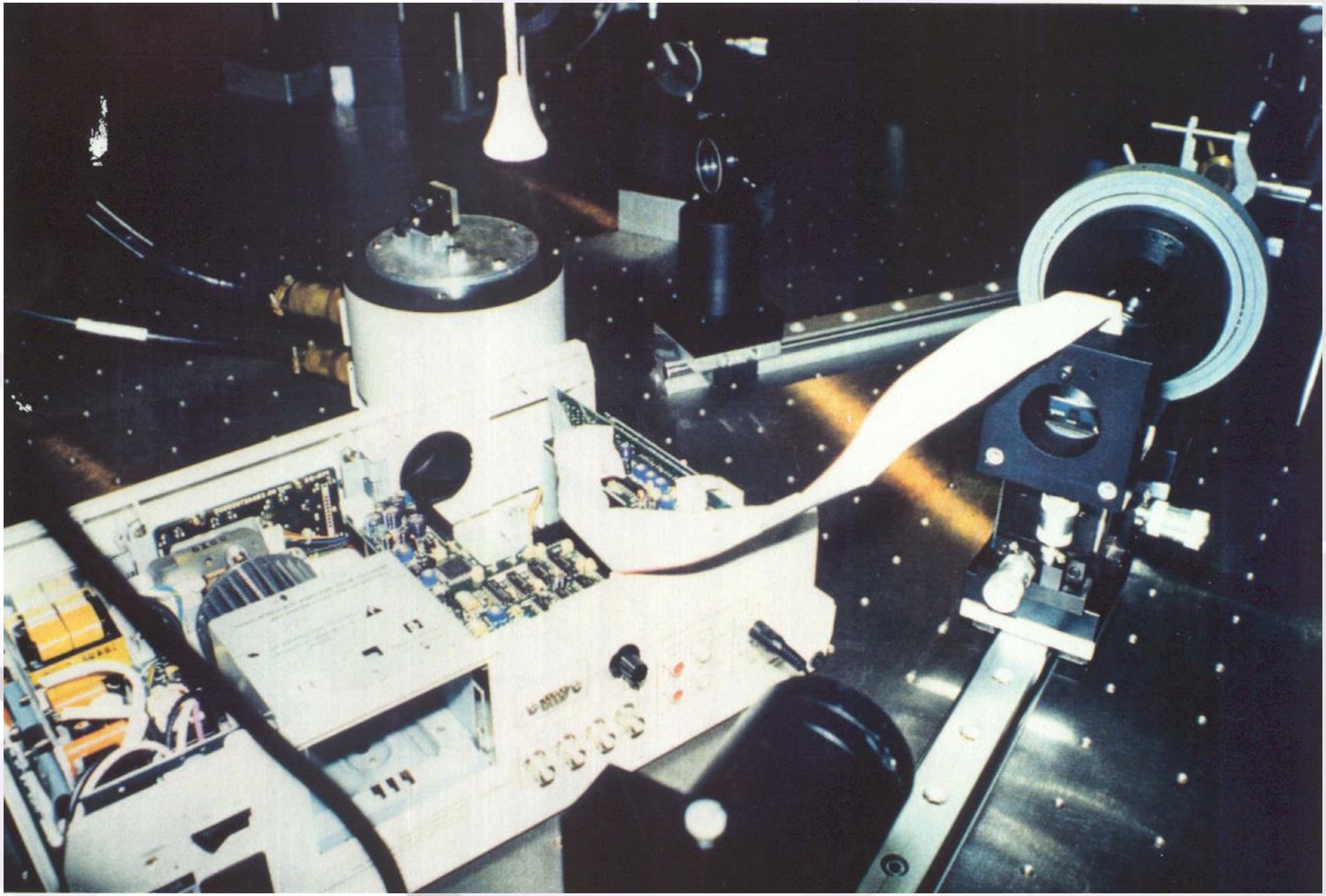
Seiko-Epson VPJ700 LCTV



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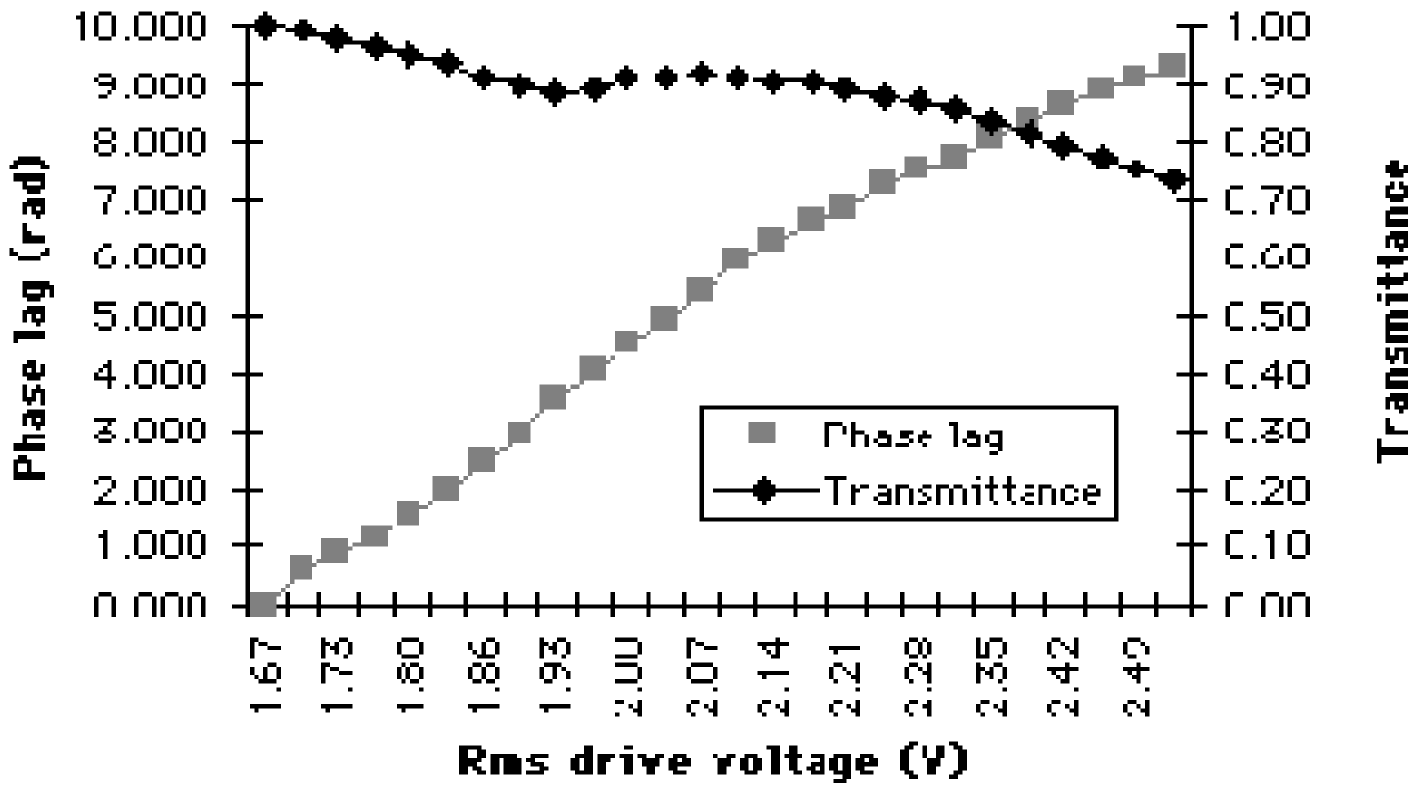
Phase Lag and Normalised Transmittance Versus Grey Level (green LCTV)



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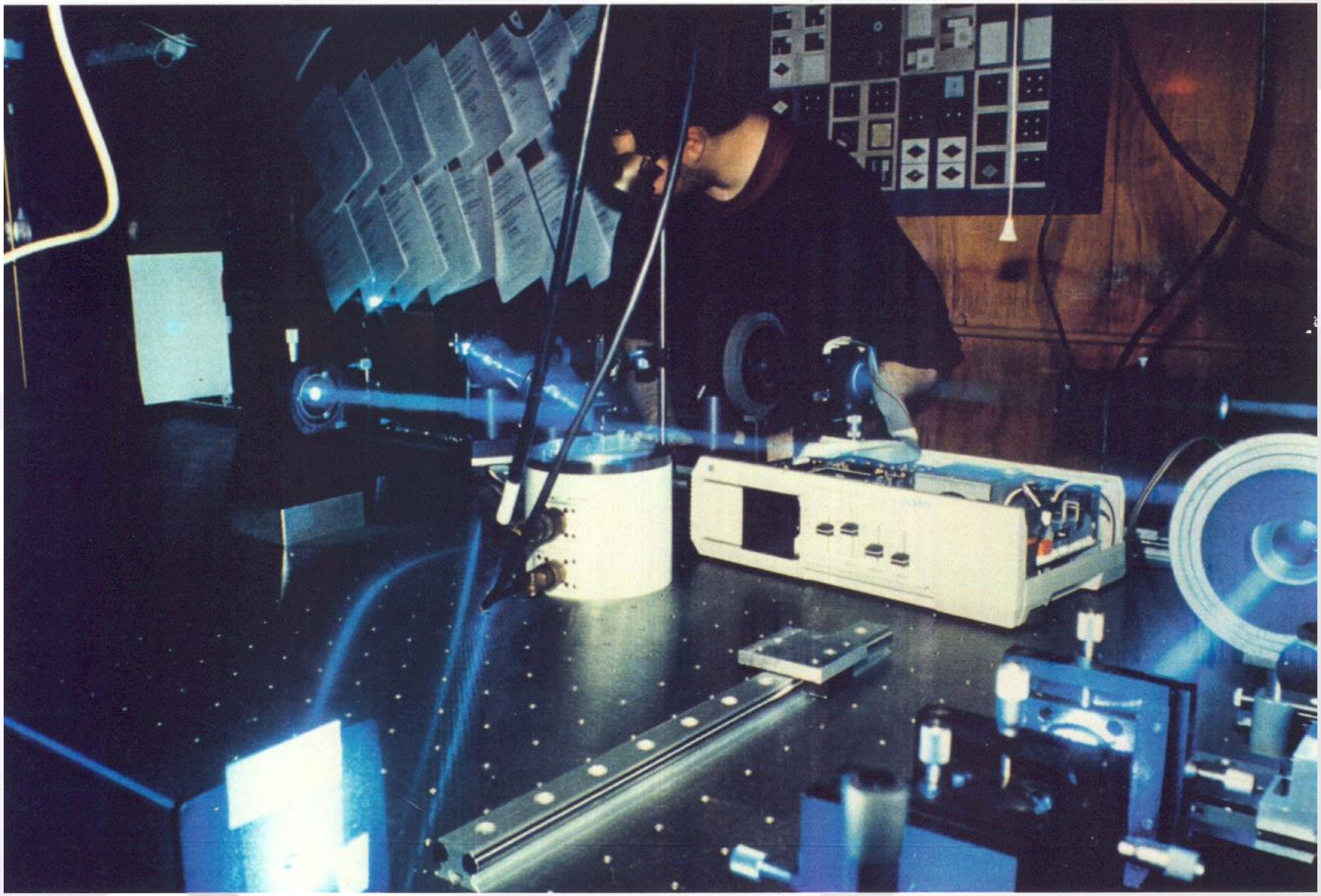
Volume Hologram Recording System



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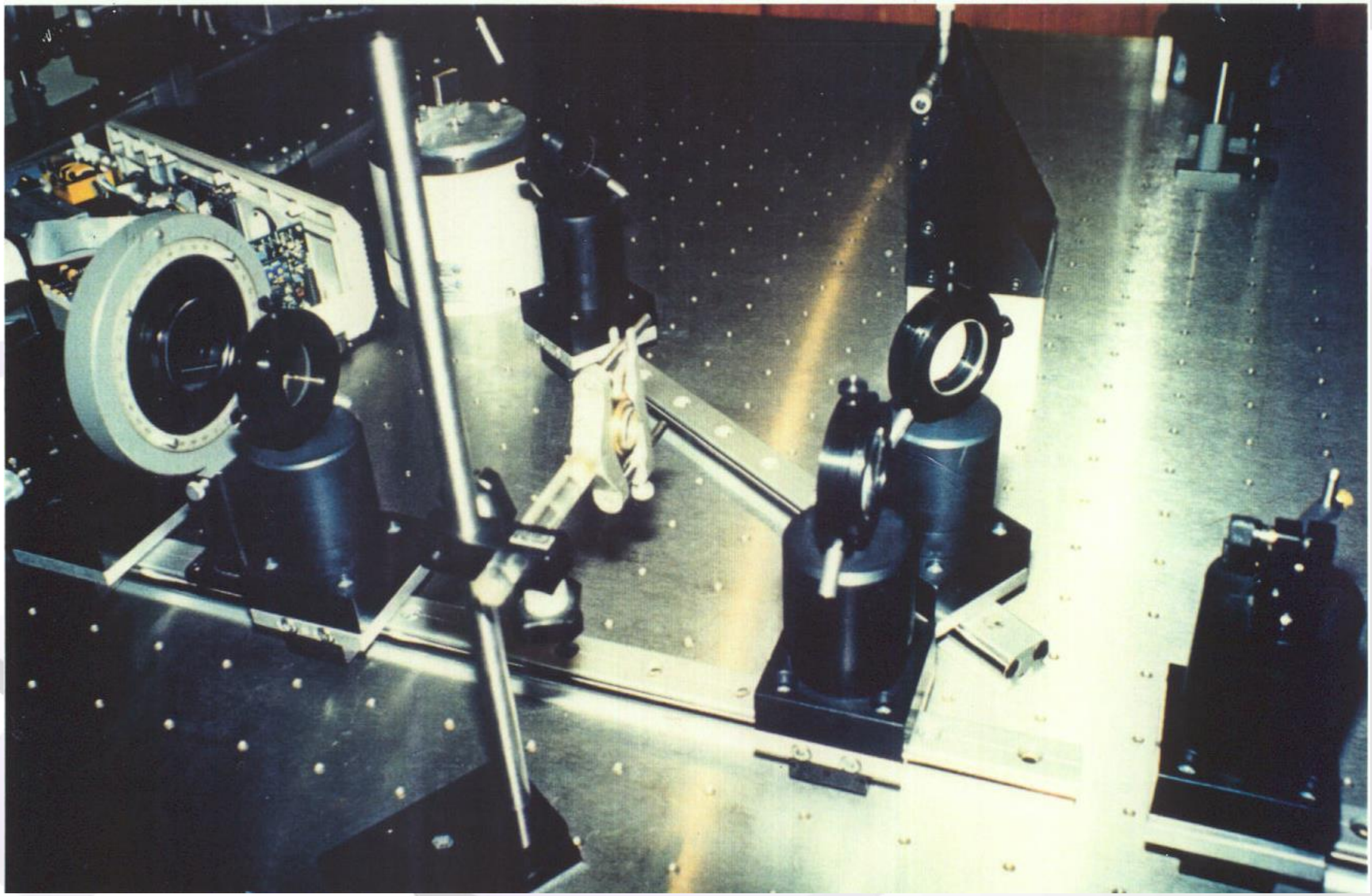
Volume Hologram Recording System



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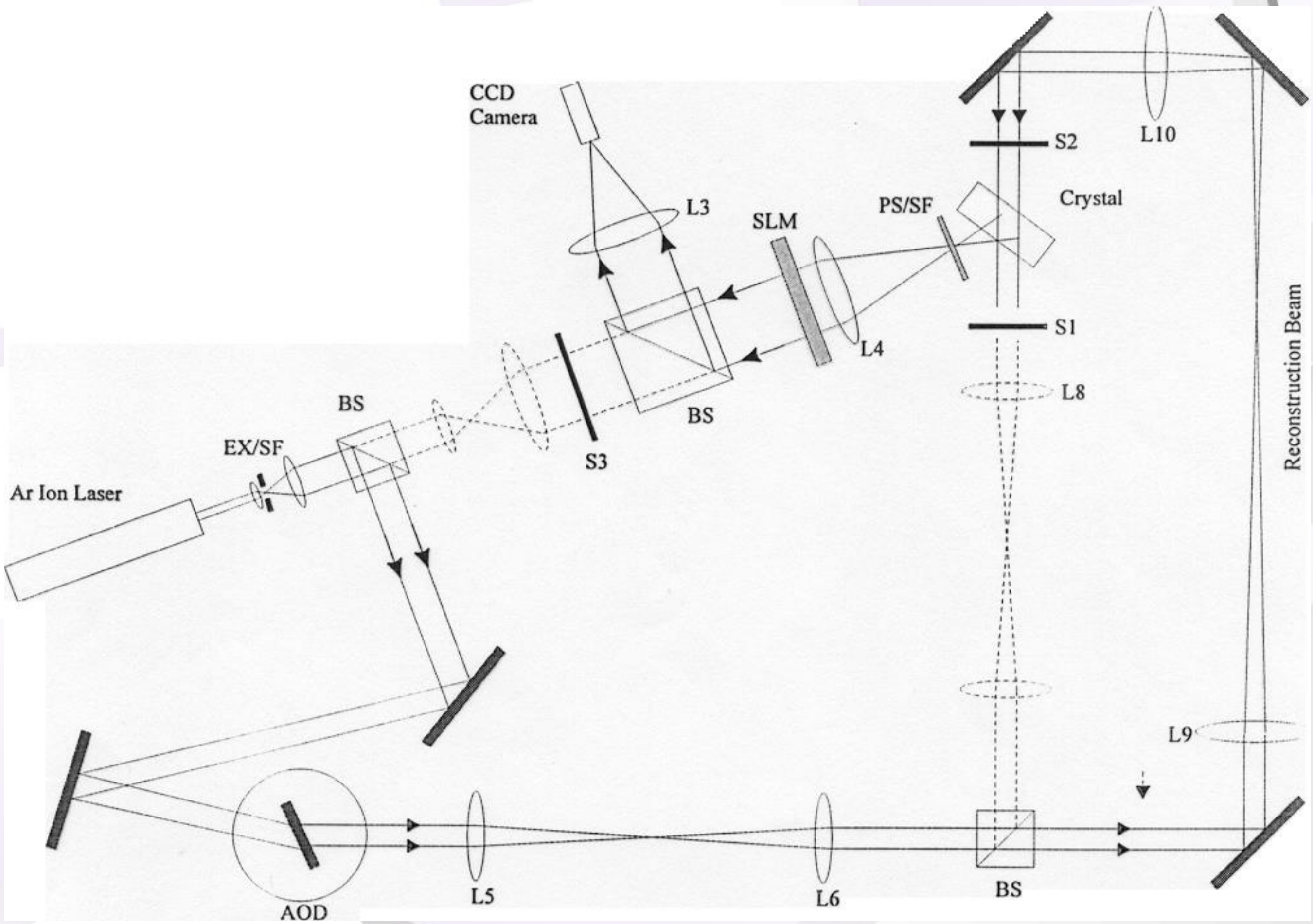
Schematic of Hybrid Optical/Digital Correlator Experimental Layout in Read Mode



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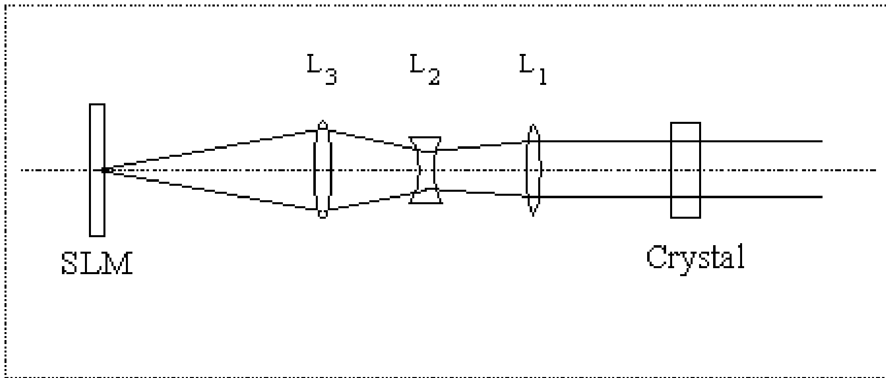
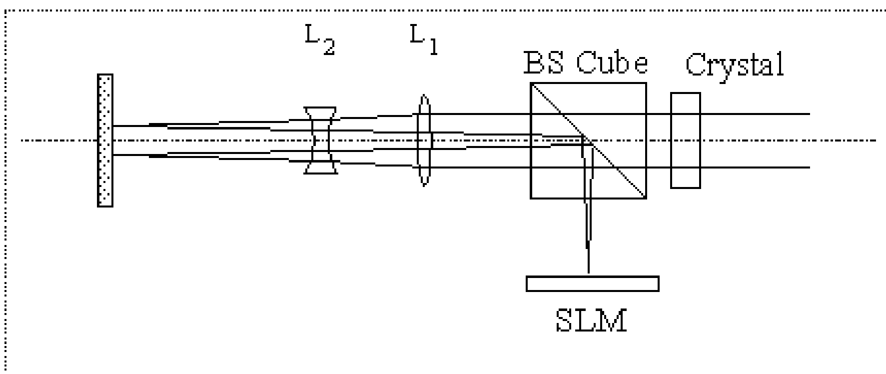
Optical Design

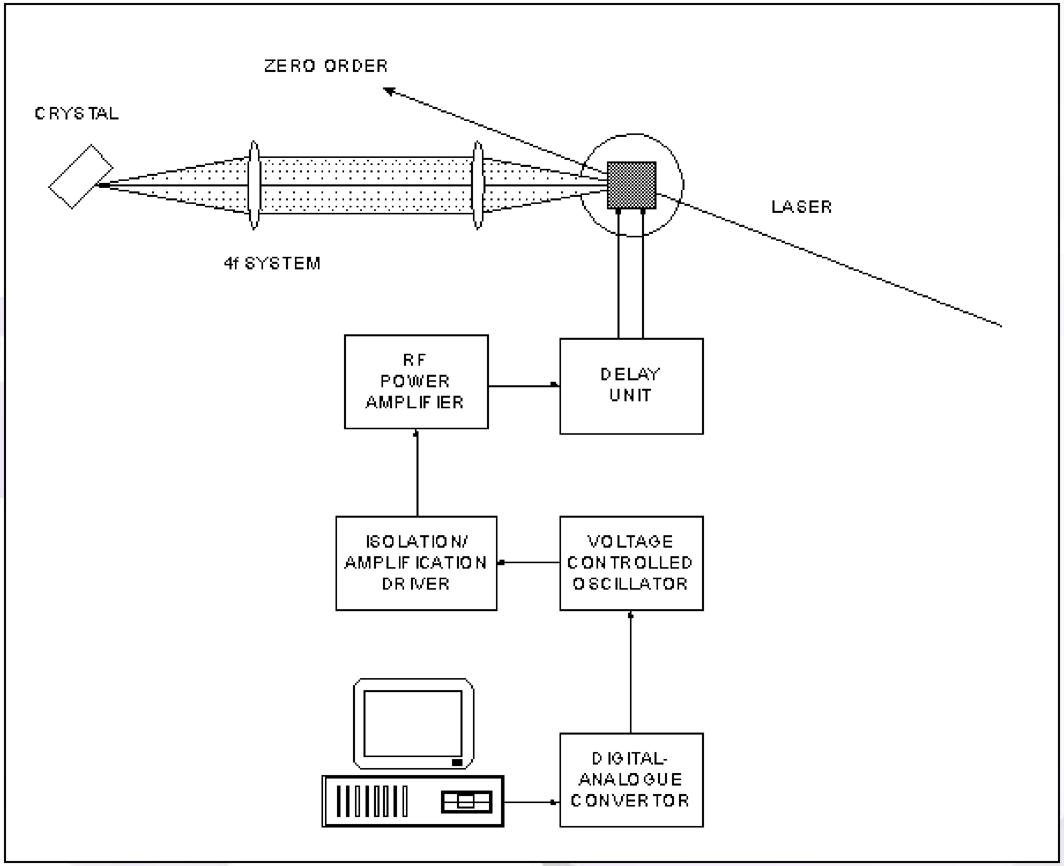


3 Lens Design



Symmetrical 2 Lens Design

TeO_2 Acousto-Optic Scanner



LS1100 from Isomet

Optimised to run at 488 nm with anti reflection coatings

Active aperture is 9 mm

Scan Angle 2.4 deg, random access time of 15 microseconds

Maximum playback speed 24,000 images/s

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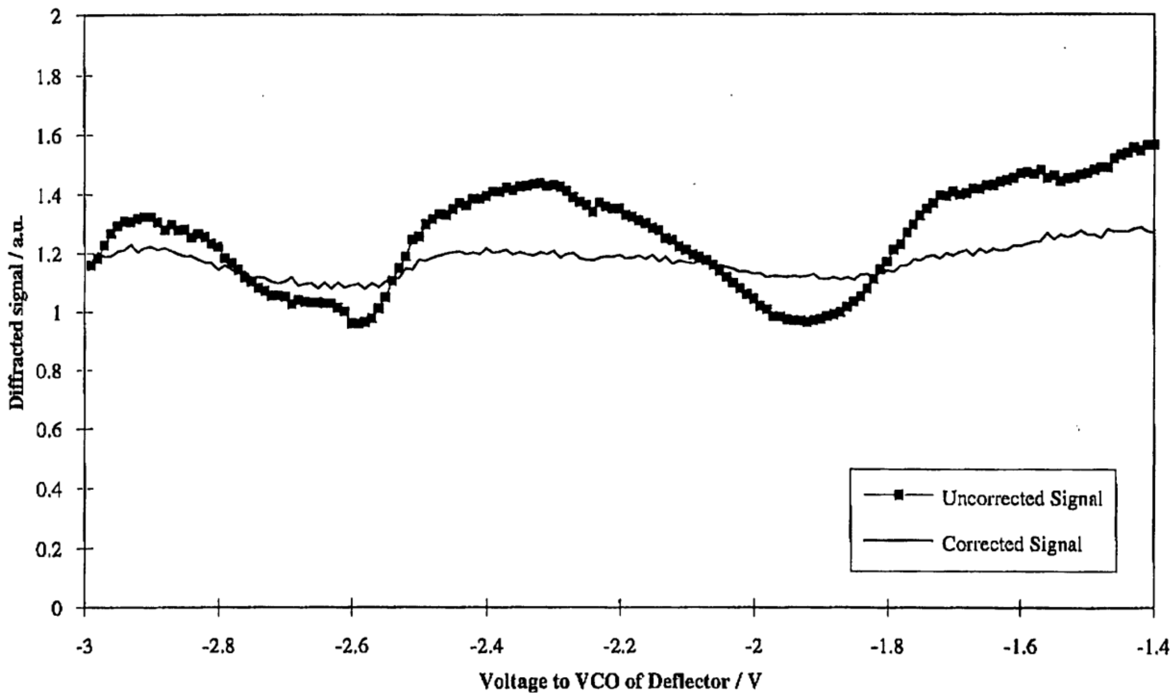
Acousto-Optic Cell Diffraction Efficiency



Variation of Diffracted Intensity from A/O Cell and Look-up Table Correction

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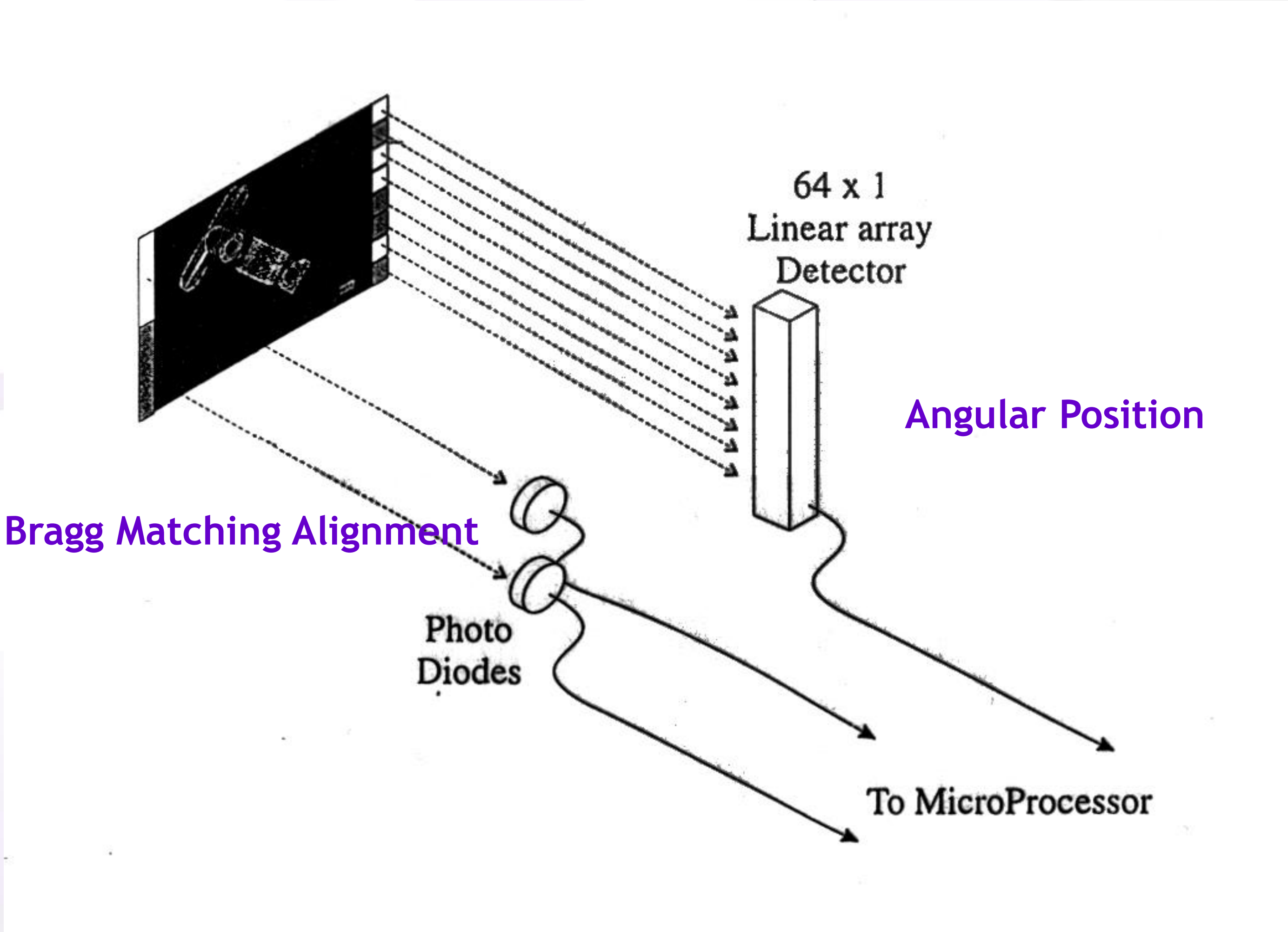
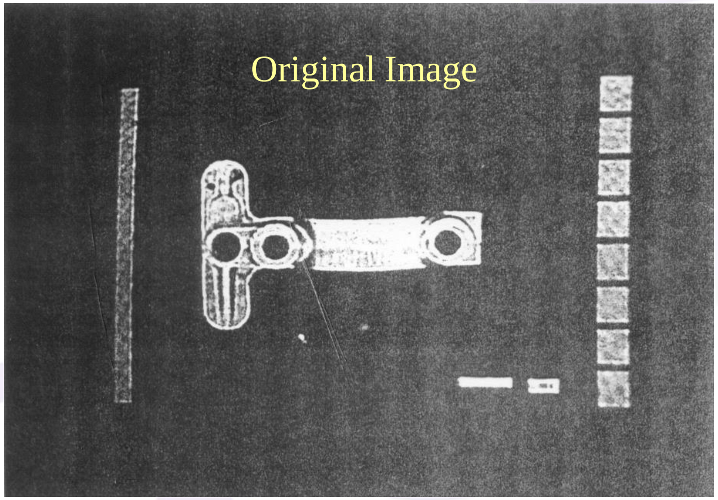
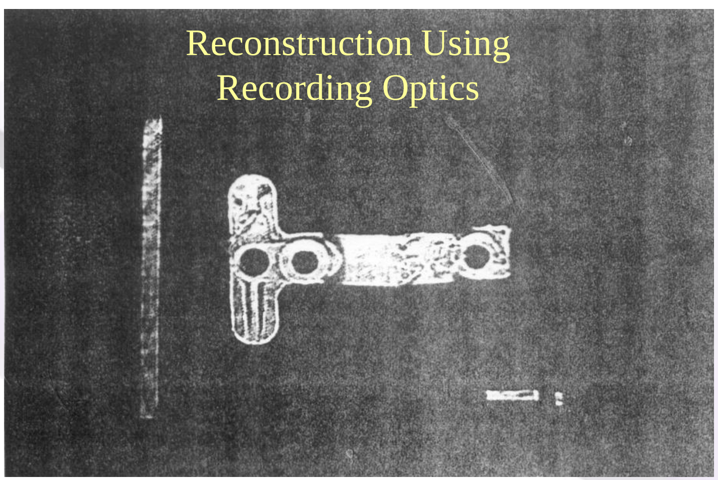
Angular Calibration of Acousto Optic Device



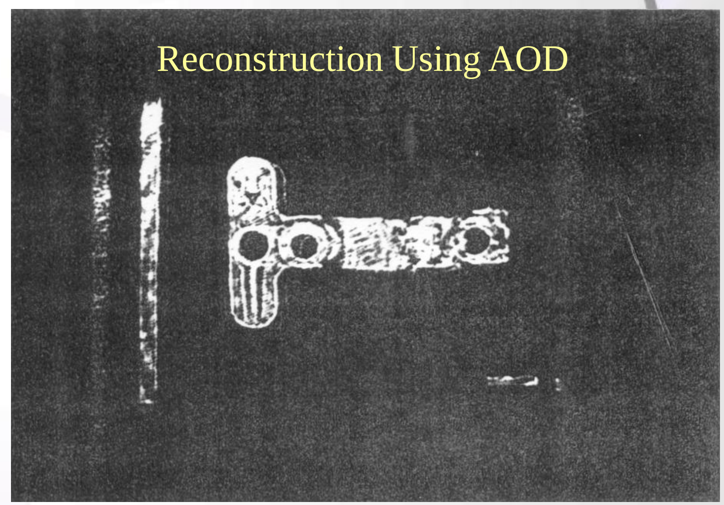
Hololographic Reconstruction



Original Image



Reconstruction Using Recording Optics



Reconstruction Using AOD

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Major Digital Sub-systems

- Fast Fourier Transform Board based on the Sharp LH9124 chip set
- High Frame Rate FPGA Based Image Processing Board, the Imaging board incorporates 4 XiLinx FPGA devices and is used for fast correlation plane processing

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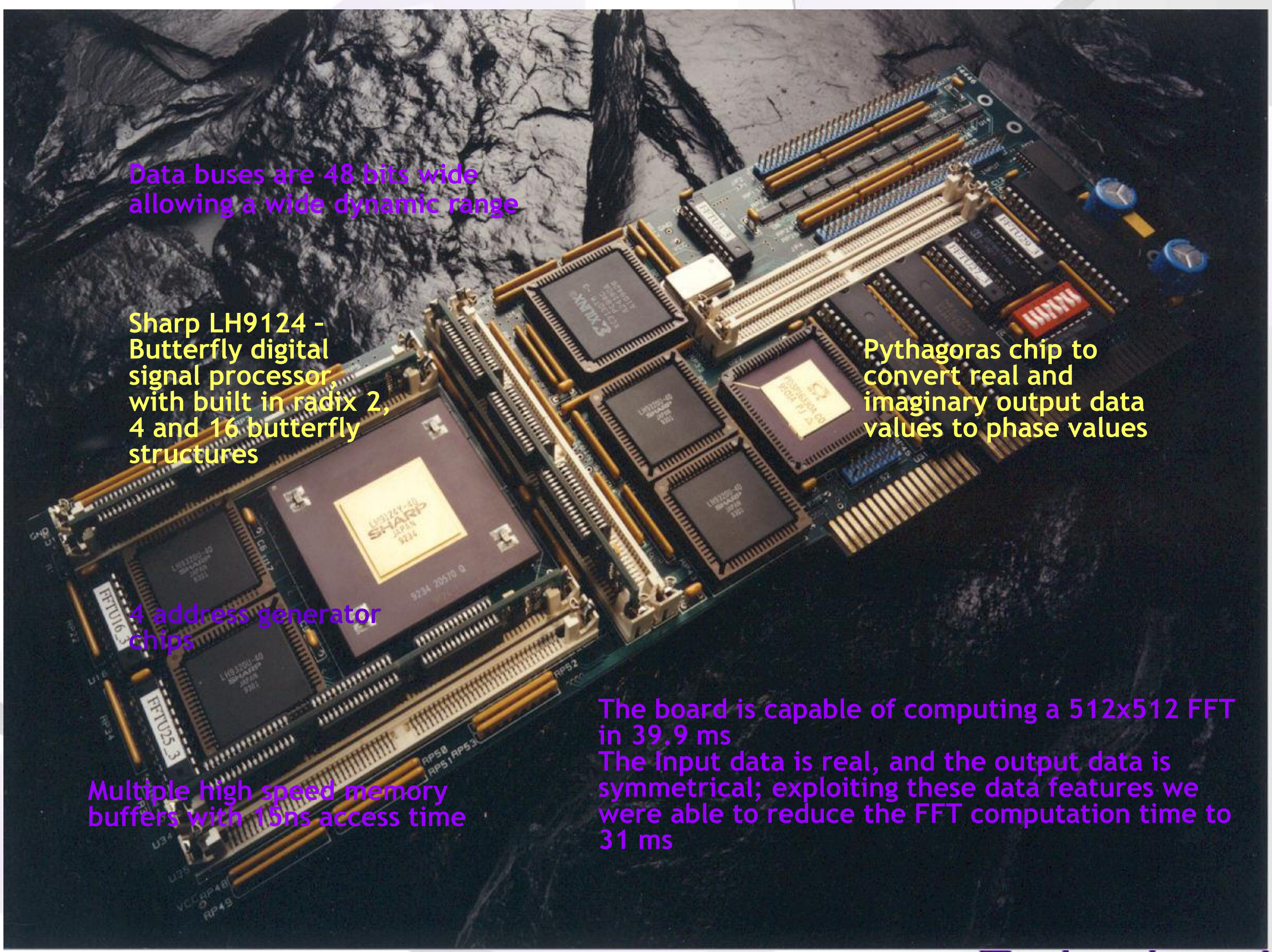
Video Rate FFT board using Sharp LH9124 DSP



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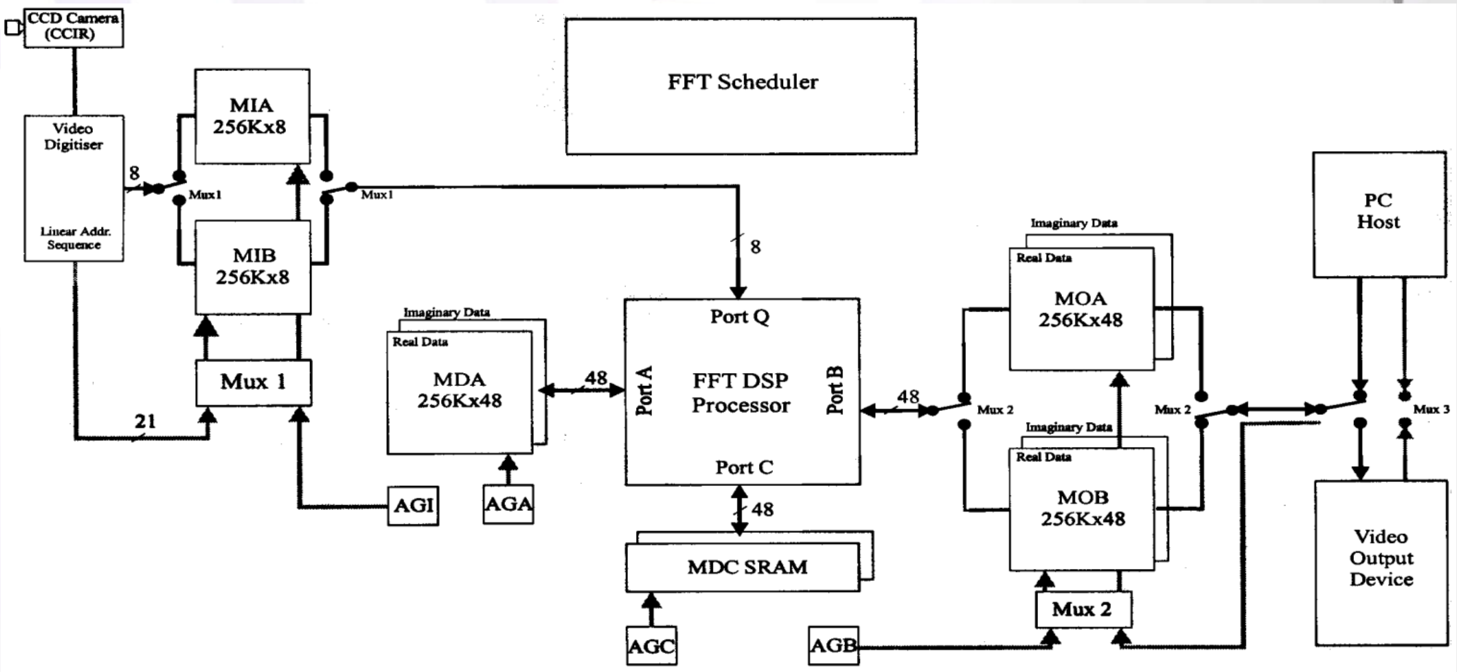

Video Rate 2D FFT Board

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High Frame Rate FPGA Based Image Processing Board

- The Imaging Board performs the following tasks using a common hardware design:
  - SLM driver for PC including real time correction of aspect ratio
  - SLM driver for FFT subsystem to display phase images
  - Correlation processing board to calculate correlation peak parameters
- Imaging boards incorporate 4 XiLinx FPGA devices
- Provides an extremely flexible internal architecture

High Frame Rate FPGA Correlation Plane Processing

- Correlation plane output produced for every correlation between input and reference template
- Location of the correlation peak identifies the position of the object in the input scene
- The task is to discriminate between good and poor correlations
- Task is completed at a rate of 2900 decisions per second (DALSA camera frame rate)

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Correlation Plane Parameters

Parameter	Description
xMin, xMax yMin, yMax	Minimum/maximum coordinates of target bounding box
xSum, ySum	Summation of X/Y coordinate of all target pixels
nSize	Number of pixels set to 1 in target

Parameter	Description	Formula
xGravity yGravity	Mean X/Y of the target	xGravity = xSum/n yGravity = ySum/n
nDensity	Concentration index of all pixels set to "1" in target	$\text{nDensity} = \dfrac{\text{nSize}}{((\text{xMax}-\text{xMin})\text{x}(\text{yMax}-\text{yMin}))}$

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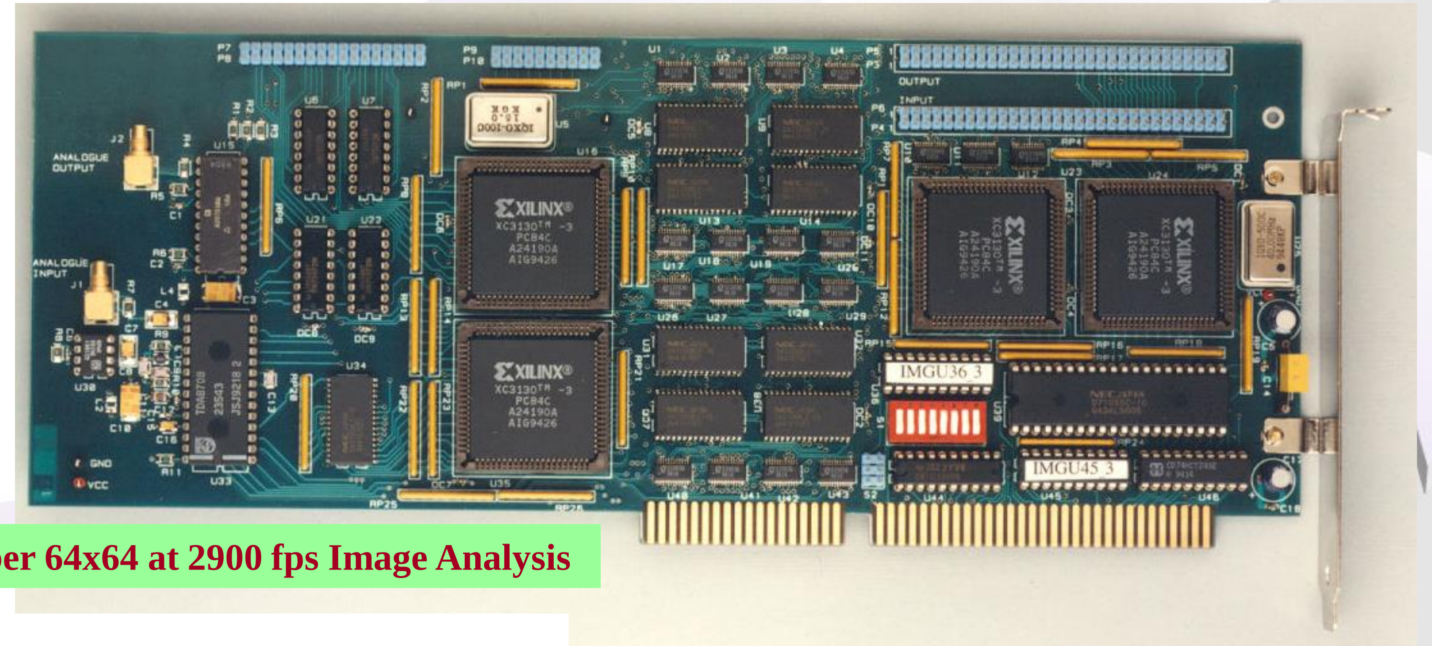
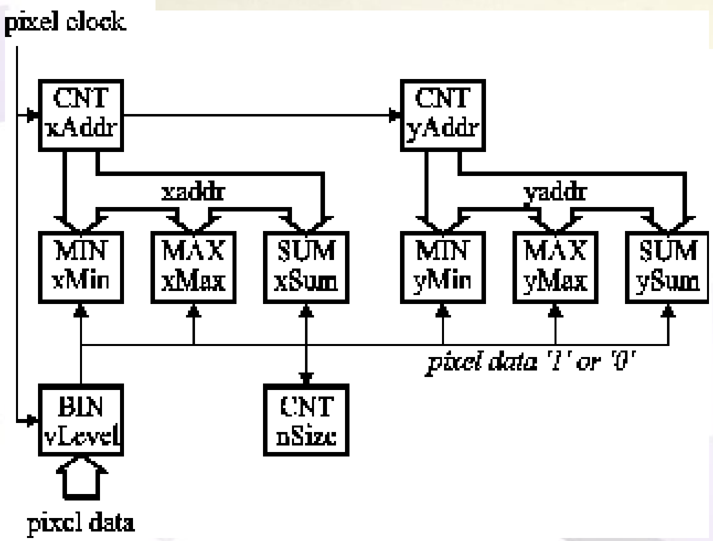
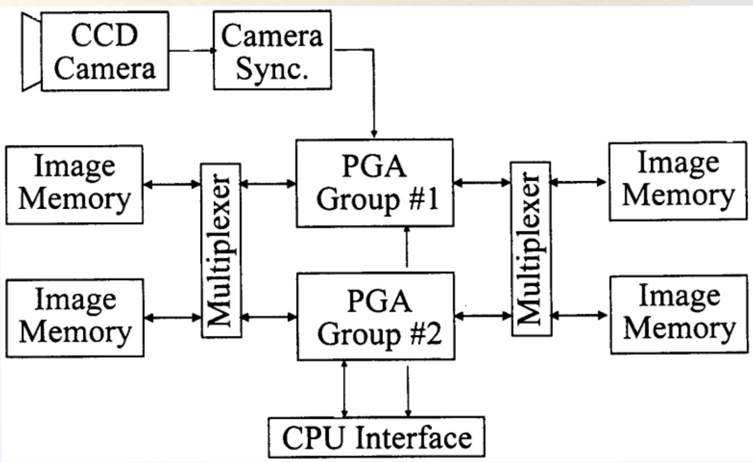
High Frame Rate FPGA Based Image Processing Board



Frame Grabber 64x64 at 2900 fps Image Analysis





The PGA's tackle tasks performed on every pixel in the image:
summation, counting, comparisons and logic operations

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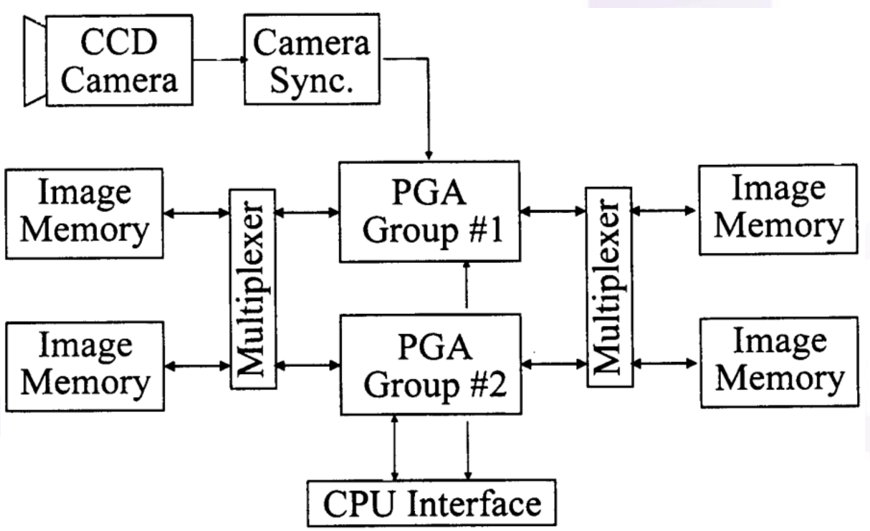
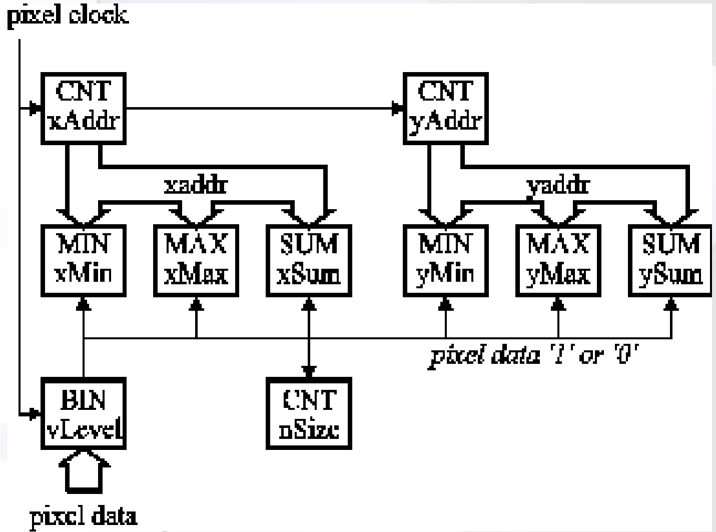
High Frame Rate FPGA Correlation Plane Processing





Determine a threshold level for the image

Threshold must be adaptable to compensate for variations in the correlations image, essential for filtering out the noise floor

Output from this process is a binary image all pixels > threshold are mapped to "1" and all others to "0"

Algorithm implemented in phase two derives multiple correlation peak parameters

A peak density parameter, nDensity, is used to quantify the quality of the correlation peak

Peak density is a function of the number and extent of "1" pixels

Functions such as division, not required for each pixel, are executed by the host central processing unit

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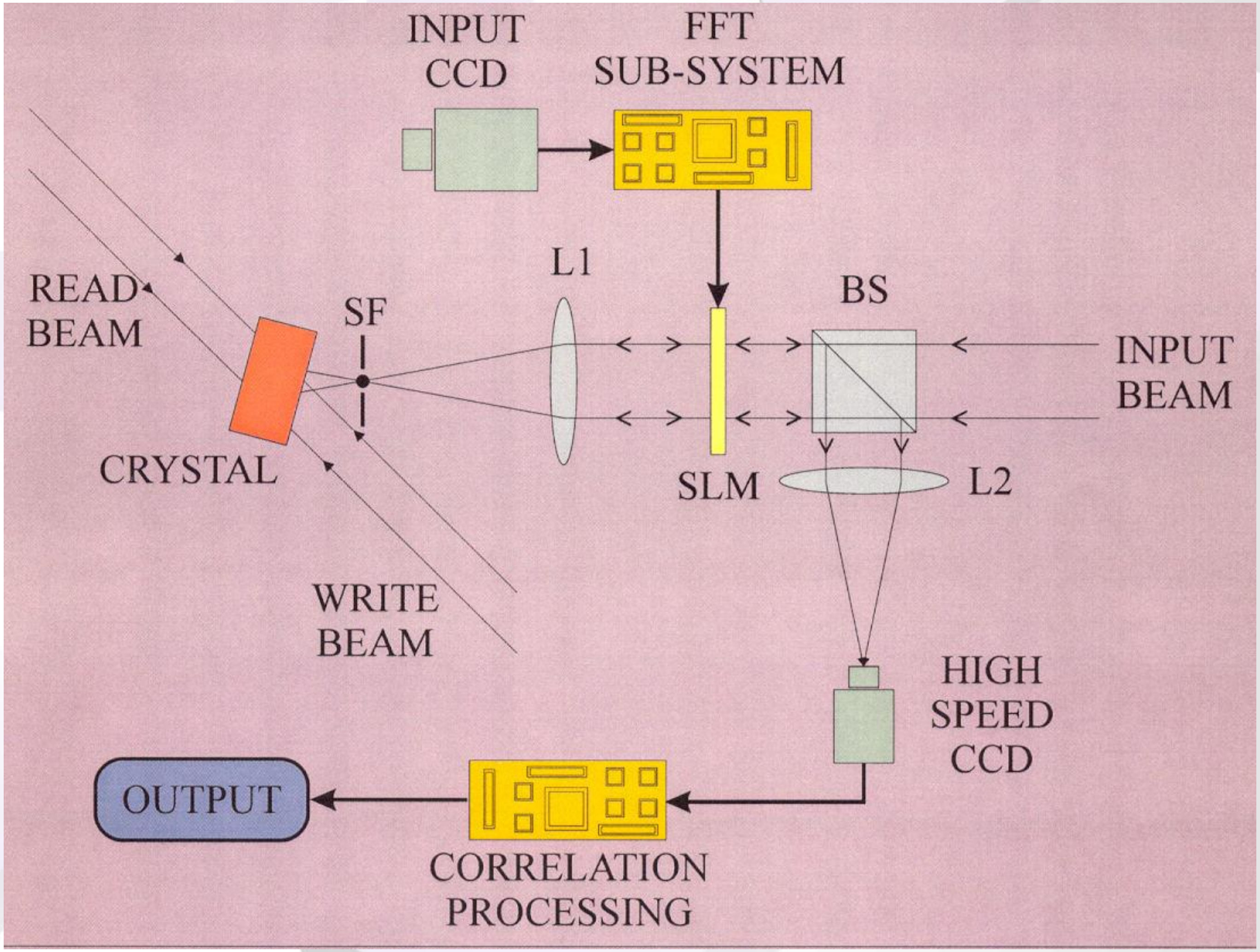
Correlator Schematic



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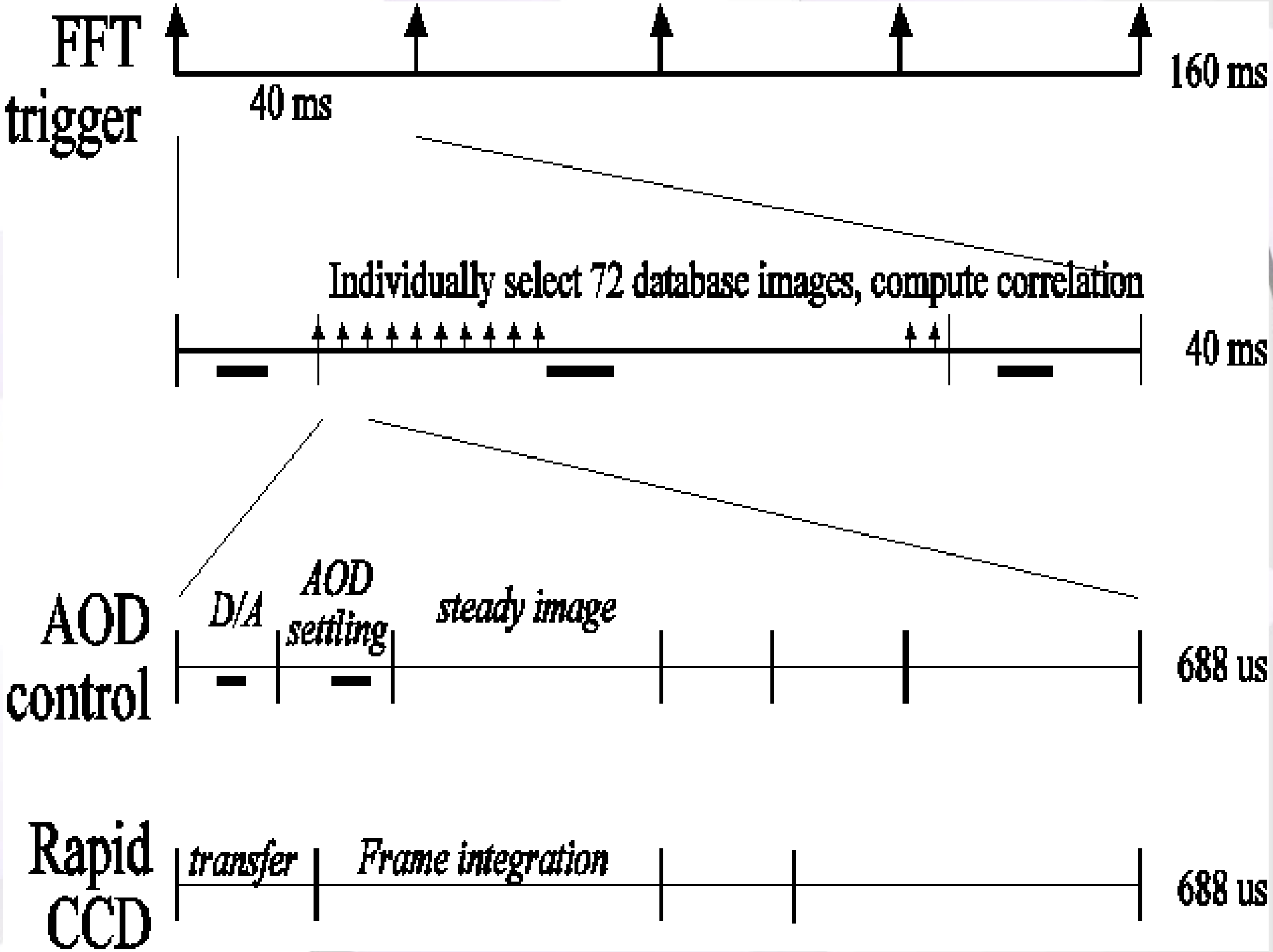
System Operation



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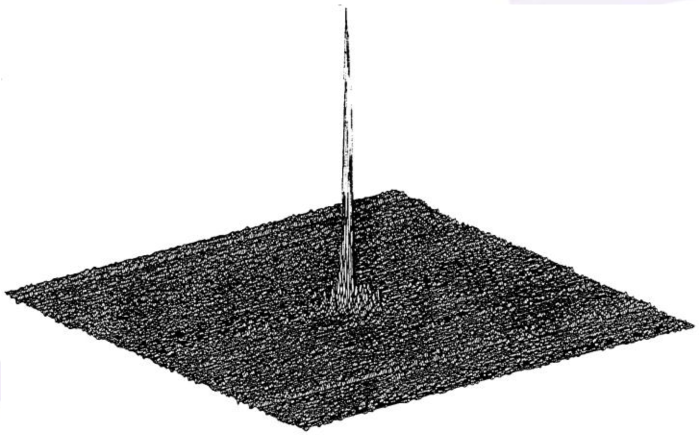
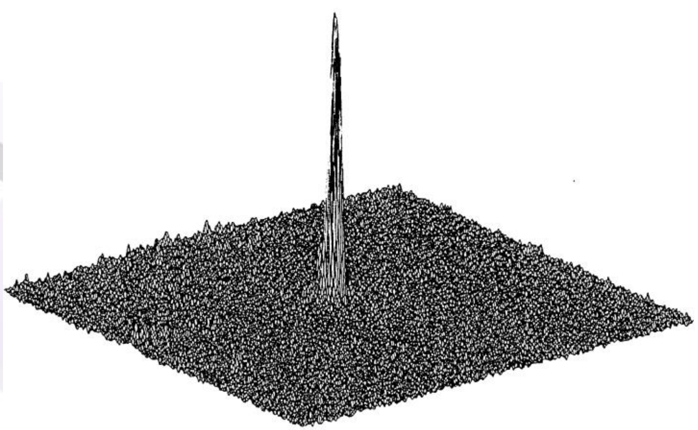
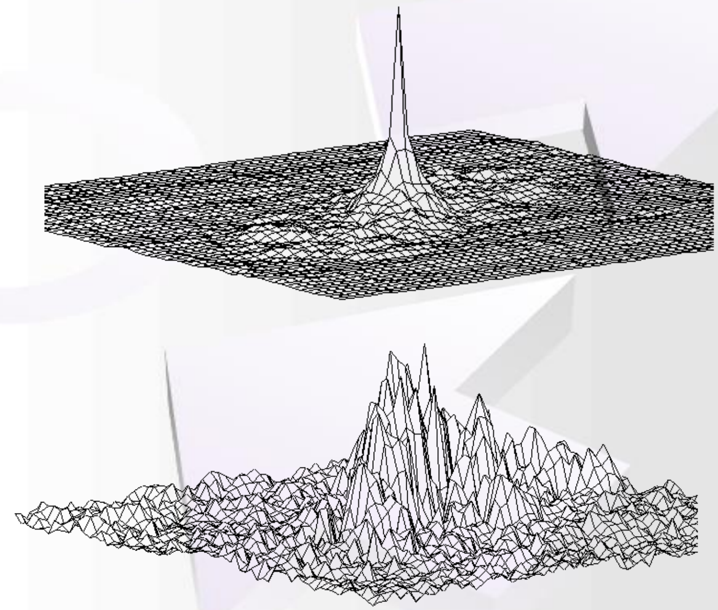
Typical Correlation Outputs



Autocorrelation of Test Component



Cross correlation with Synthetic Discriminant Function Multiplexed Filter



Cross correlations with rotated components

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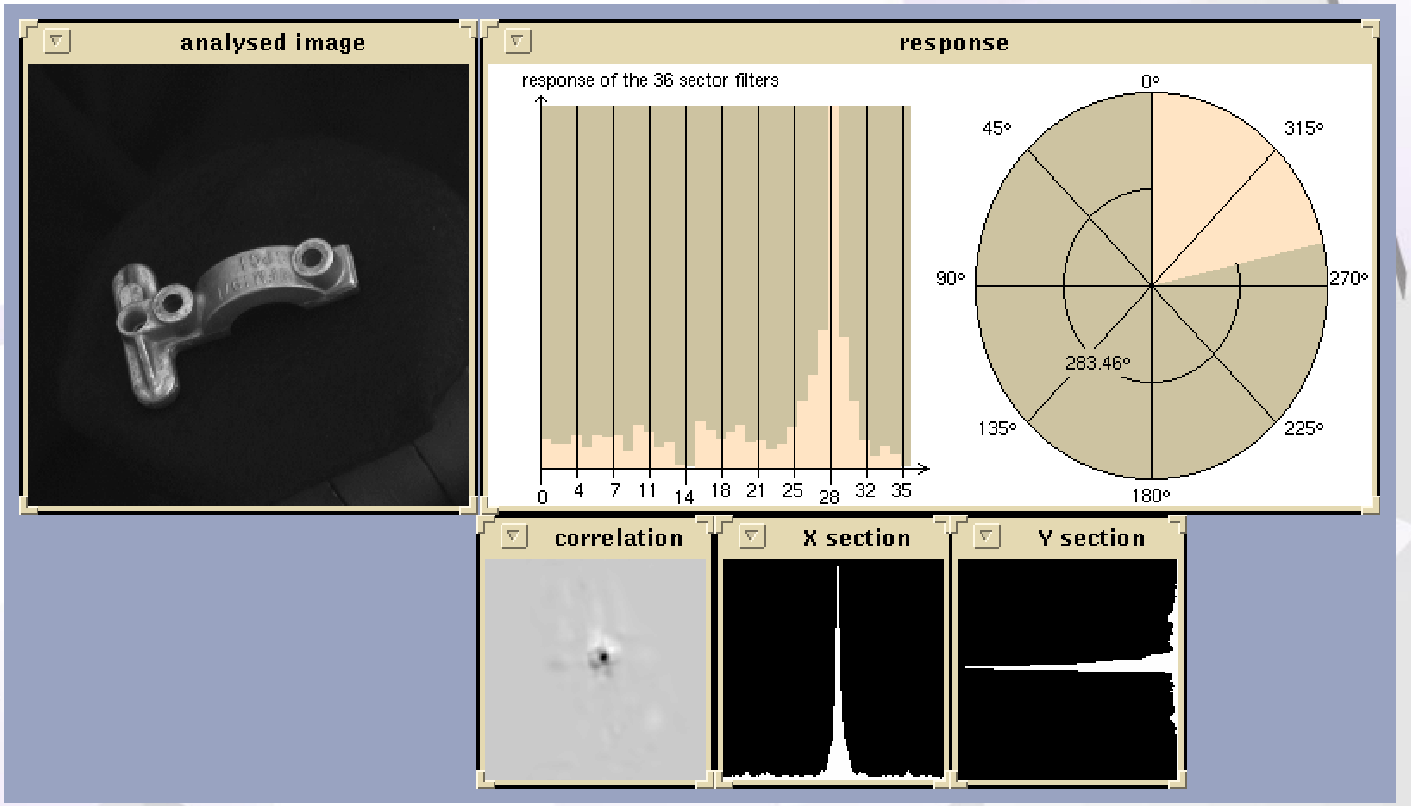
Orientation Determination Using an SDF Filter



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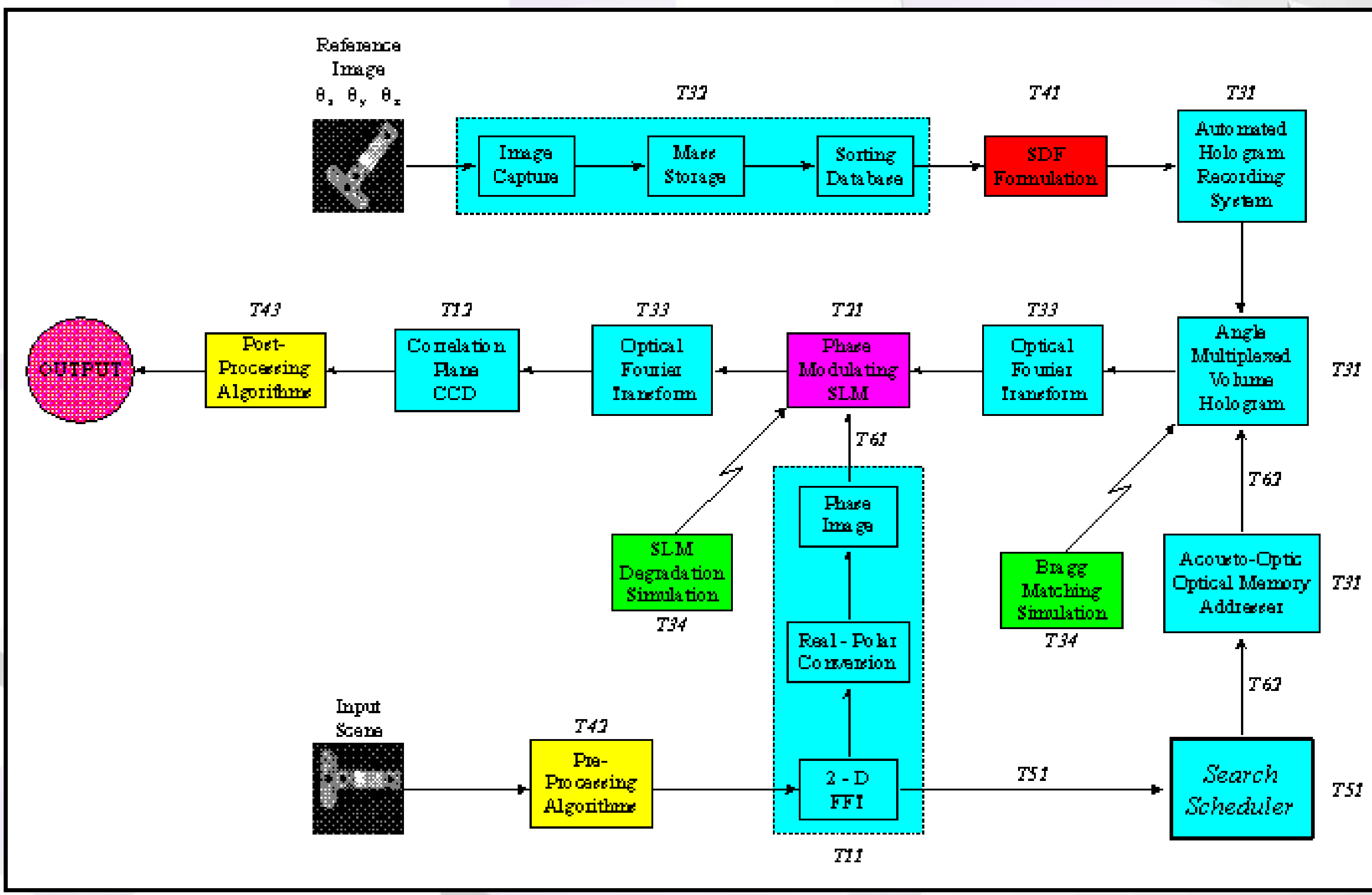
Research Tasks



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PCI Bus Hybrid Digital/Optical Computer using an Analogue Ferroelectric Liquid Crystal Spatial Light Modulator

UNIVERSITY OF SUSSEX AT BRIGHTON

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Motivations

- Correlators offer a powerful image recognition solution
- Example application are target identification and tracking, high speed character recognition (Post Office sorting, number plate reading, banknote authentication) and many others
- Problems with them are designing filters, robustness, physical size.
- A Digital/Optical hybrid correlator is used with a full complex filter (amplitude and phase control) on a spatial light modulator (SLM).

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Filter Design

- Optical filters for correlators are often approximations, e.g.
- Phase only
- Binary phase only
- Nearest distance (TNSLM)
- A fully complex modulation method would improve this.
- We use a phase detour technique using two pixels of an analogue ferroelectric liquid crystal SLM.

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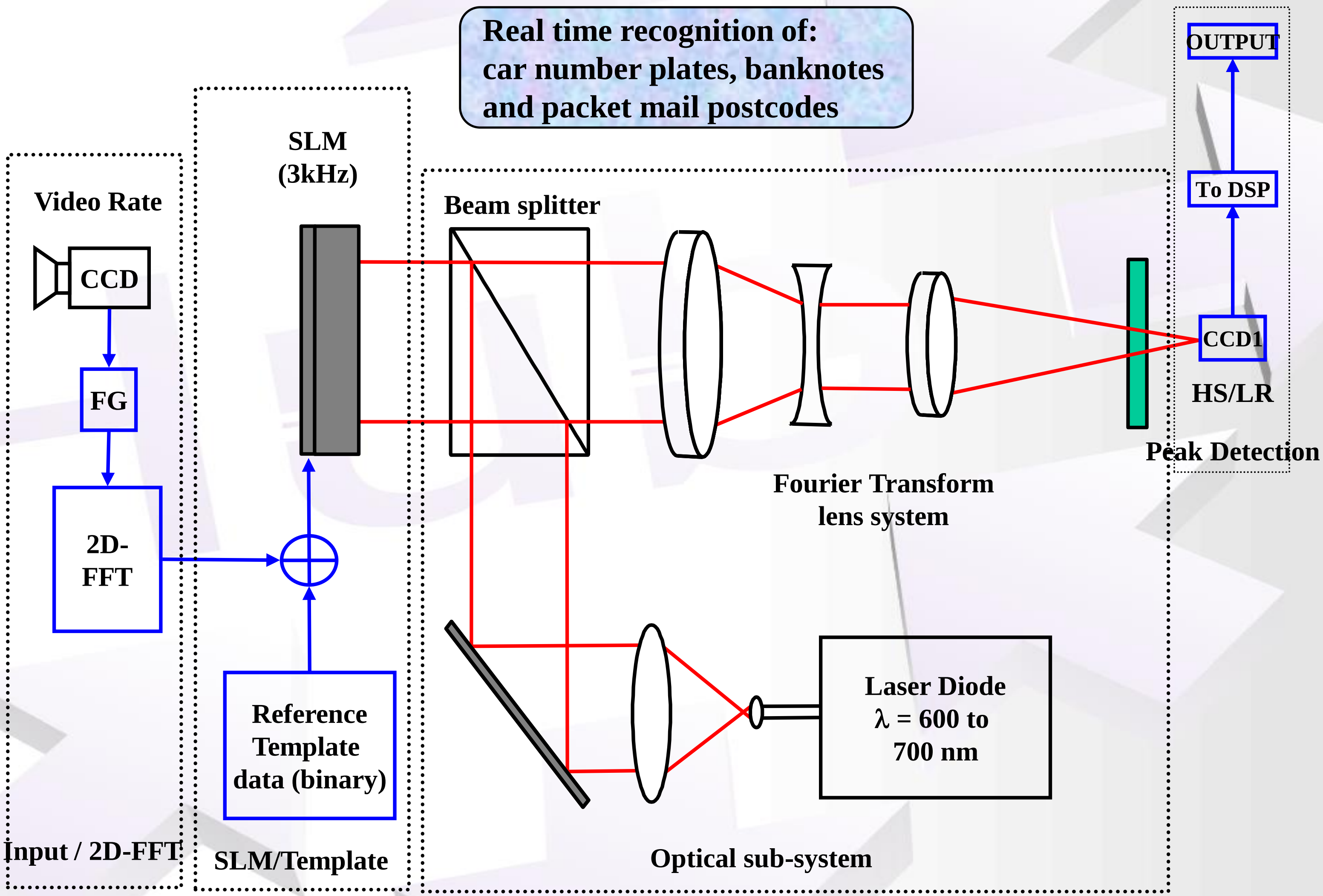
**Real time recognition of:
car number plates, banknotes
and packet mail postcodes**



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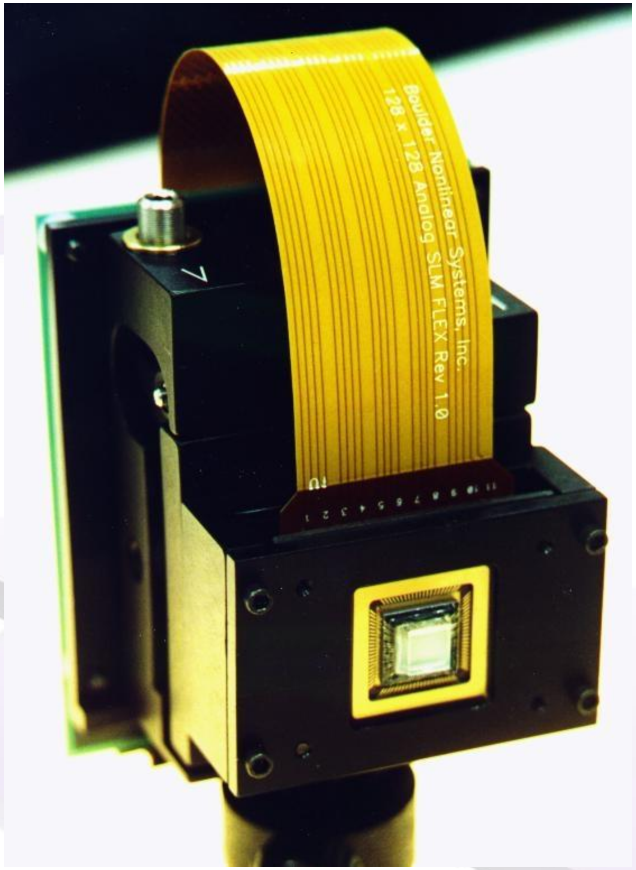
Boulder Non-linear Systems 128x128 SLM



- Liquid Crystal Type Smectic A*
- Total Array Size 5.12mm x 5.12mm
- Pixel Pitch 40μm
- Fill Factor 60%
- Frame Load Time 100 μs
- Resolution 8-bit (256 levels)
- Real axis modulation or binary phase modulation

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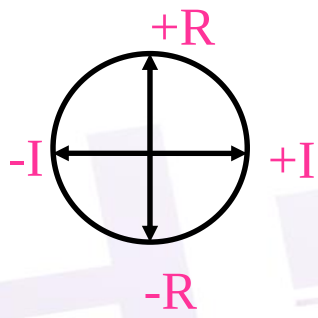
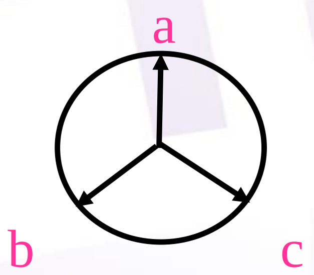
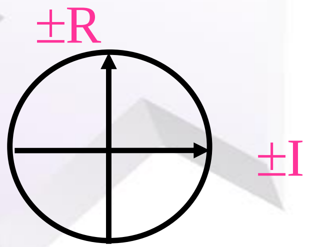
Methods to Produce Complex Modulation



+R	-I	-R	+I



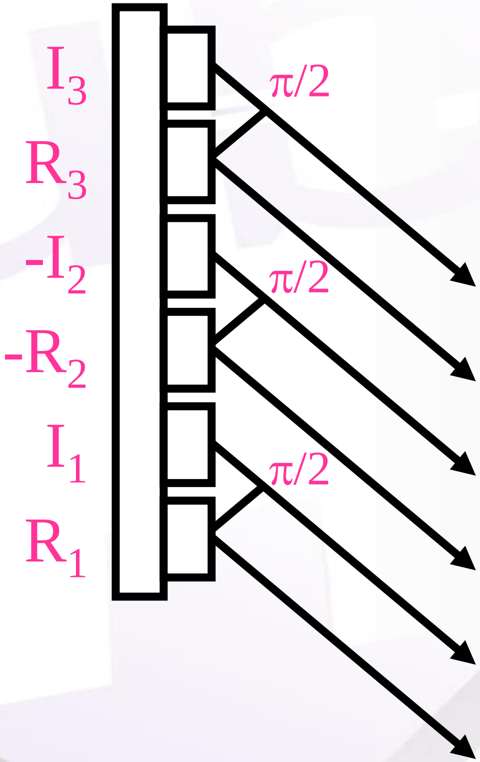
a	b	c



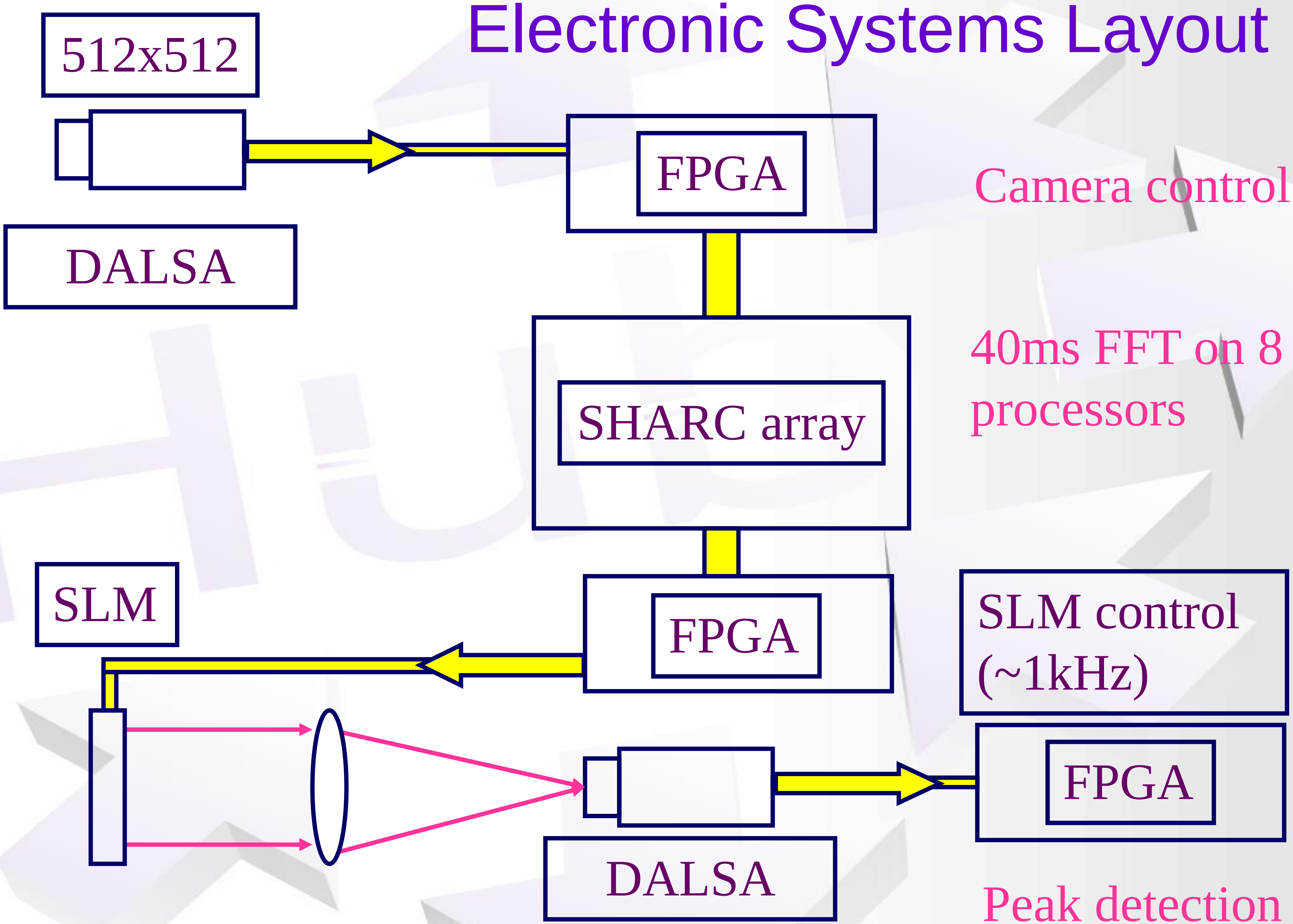
±R	±I

Complex Modulation Method with AFLC

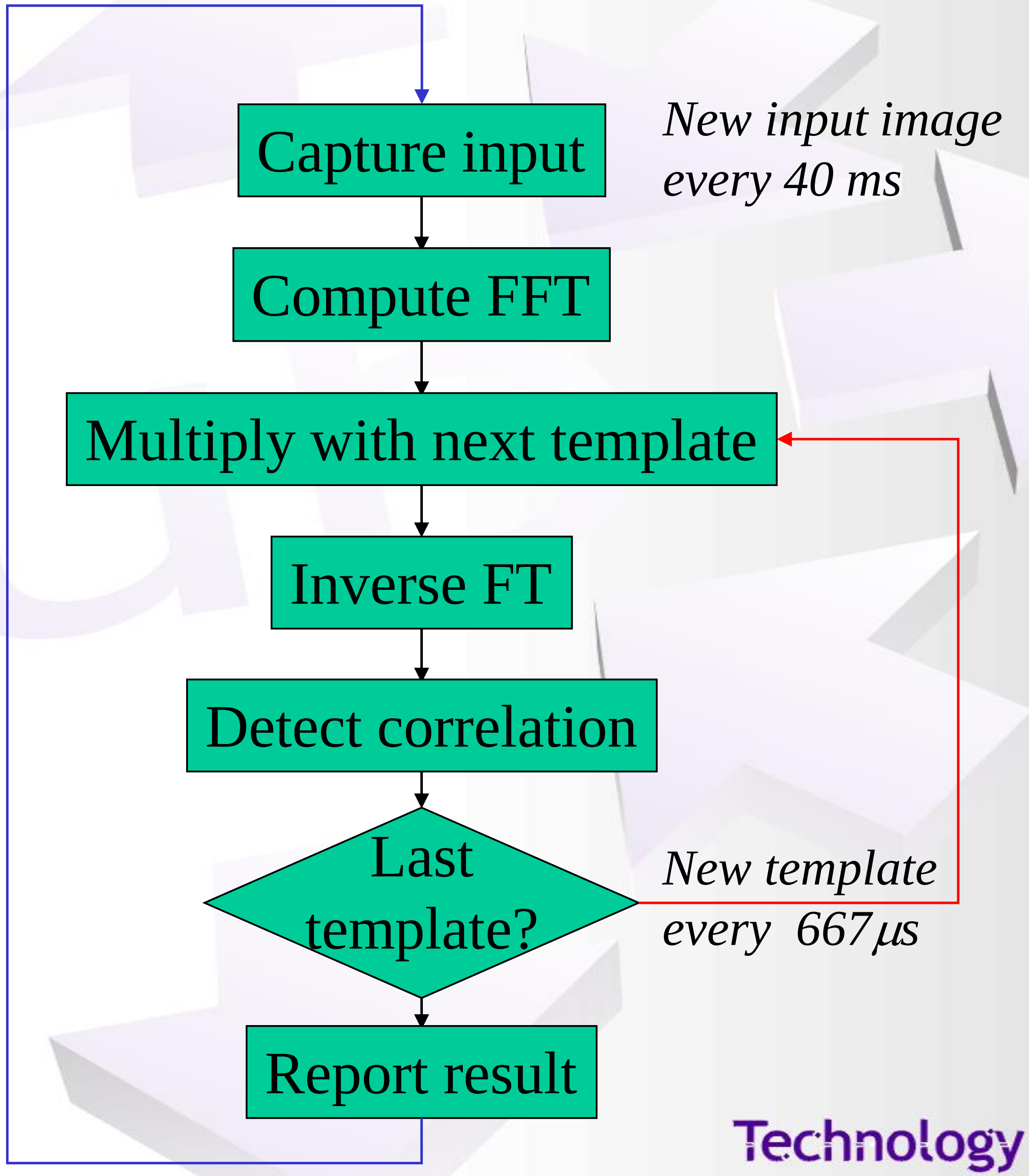
SLM gives 8 bit resolution, ie 256 level, hence the component of the polarisation vector that is horizontal can be made +ve or -ve



Electronic Systems Layout



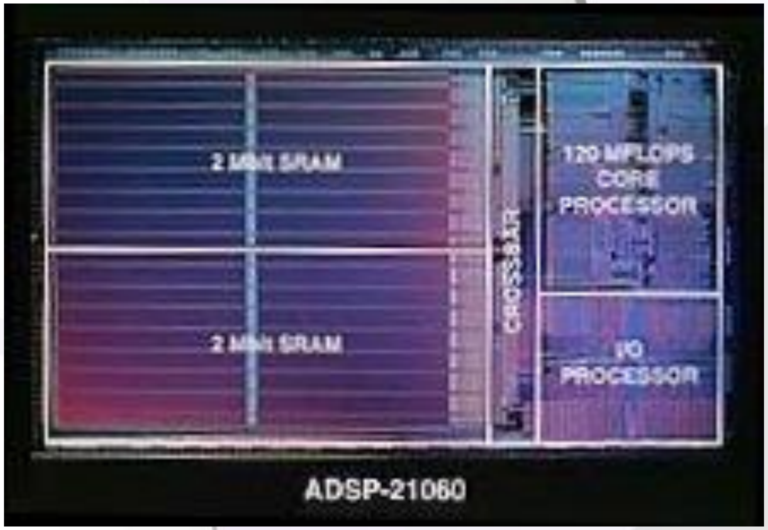
Flow Diagram



DSP Technical Specifications

ADSP 21060 - 21062

- 32-bit floating point computation unit
- 40MHz clock cycle
- 25ns instruction rate, 40MIPS
- 80 MFLOPS
- Dual ported SRAM (4Mbit or 2Mbit)
- DMA Controller - 10 channels
- C++ compiler



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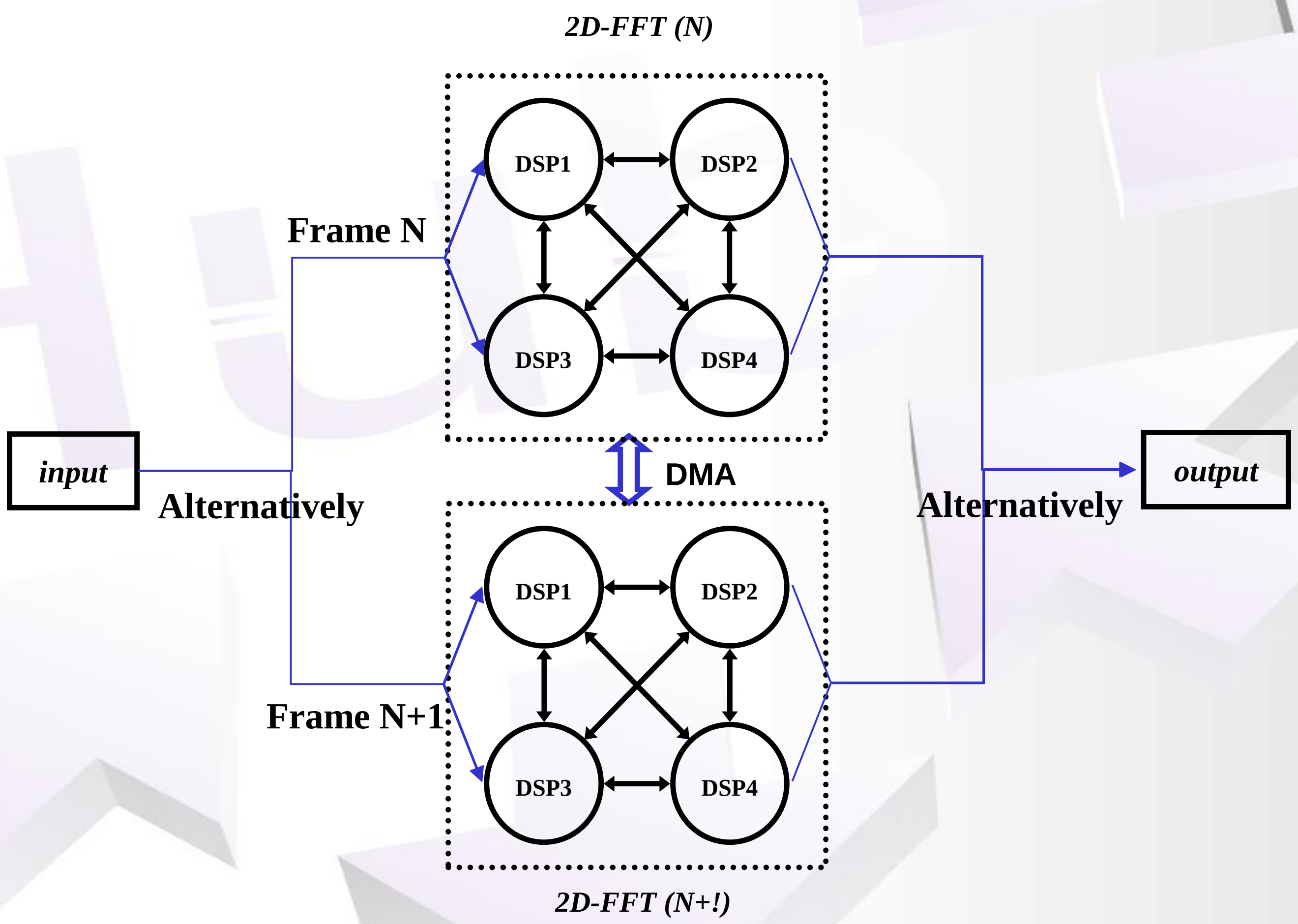
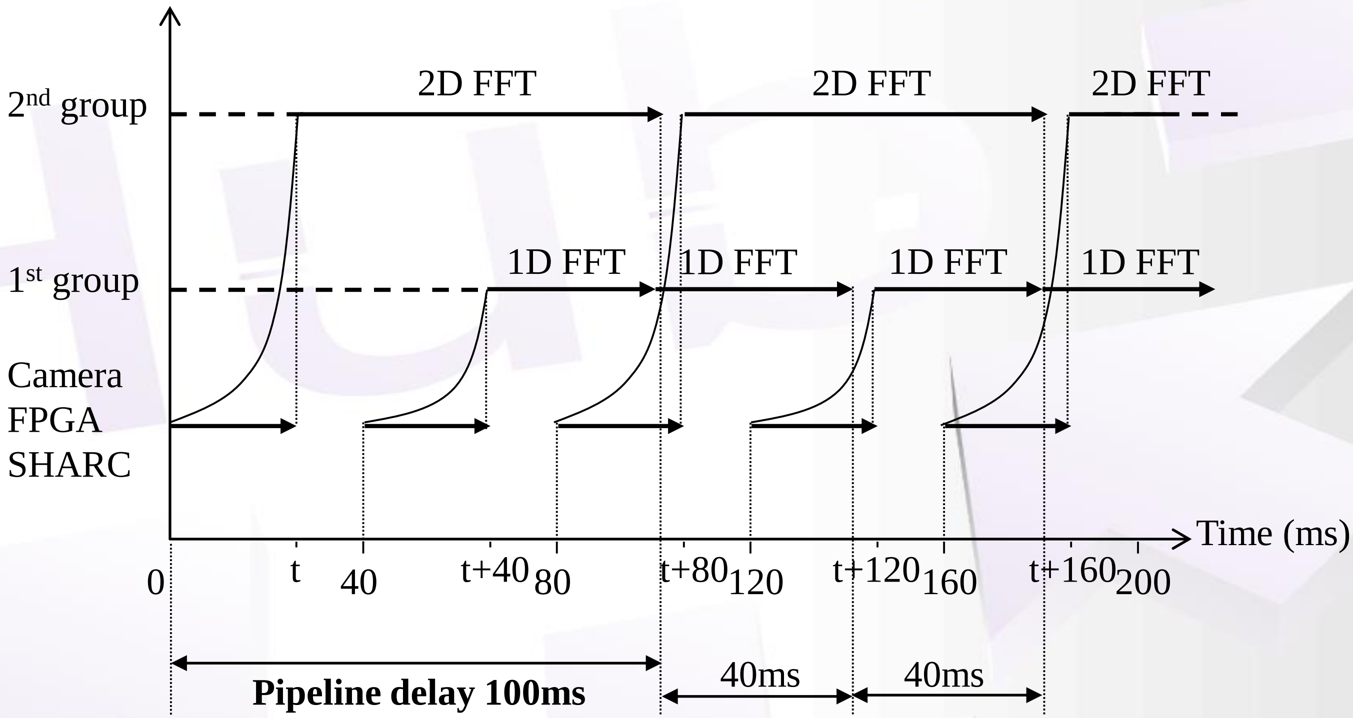
Parallel Pipeline Configuration for 2D FFT



Timing Diagram of 2D FFT



FFT rate = Input video Rate

40 ms

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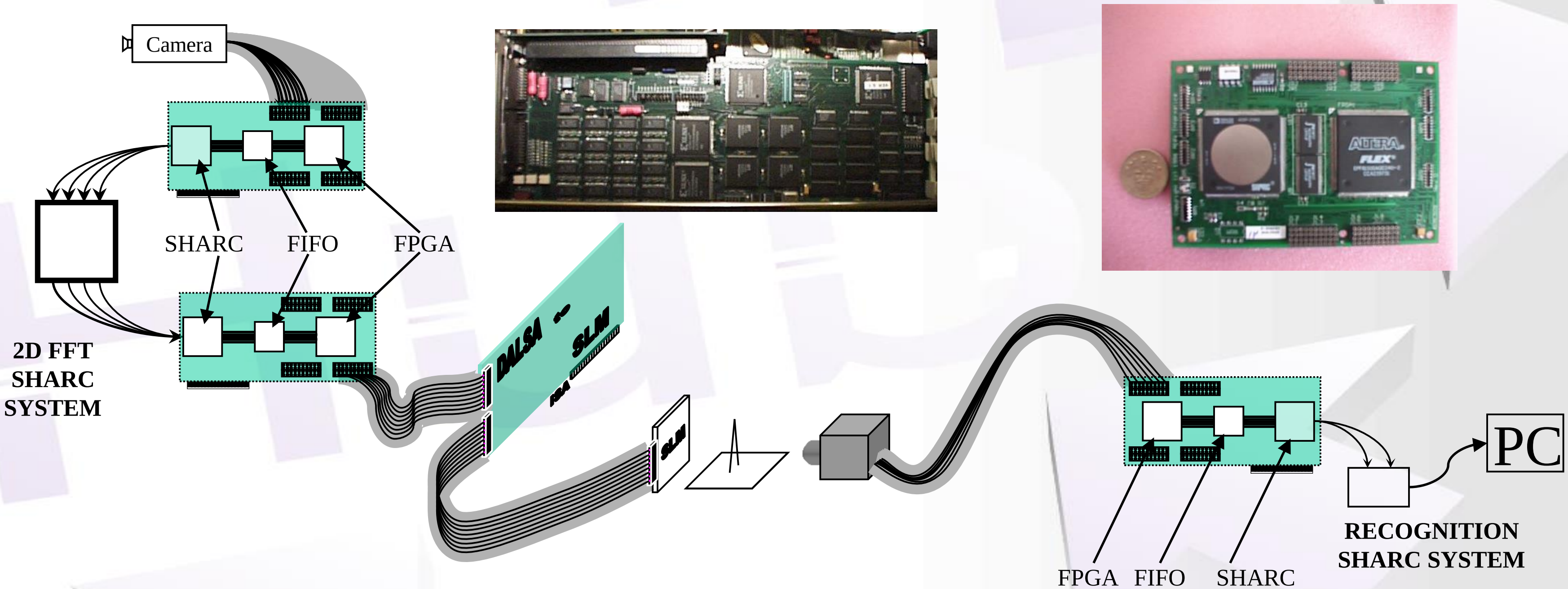
Digital FFT system

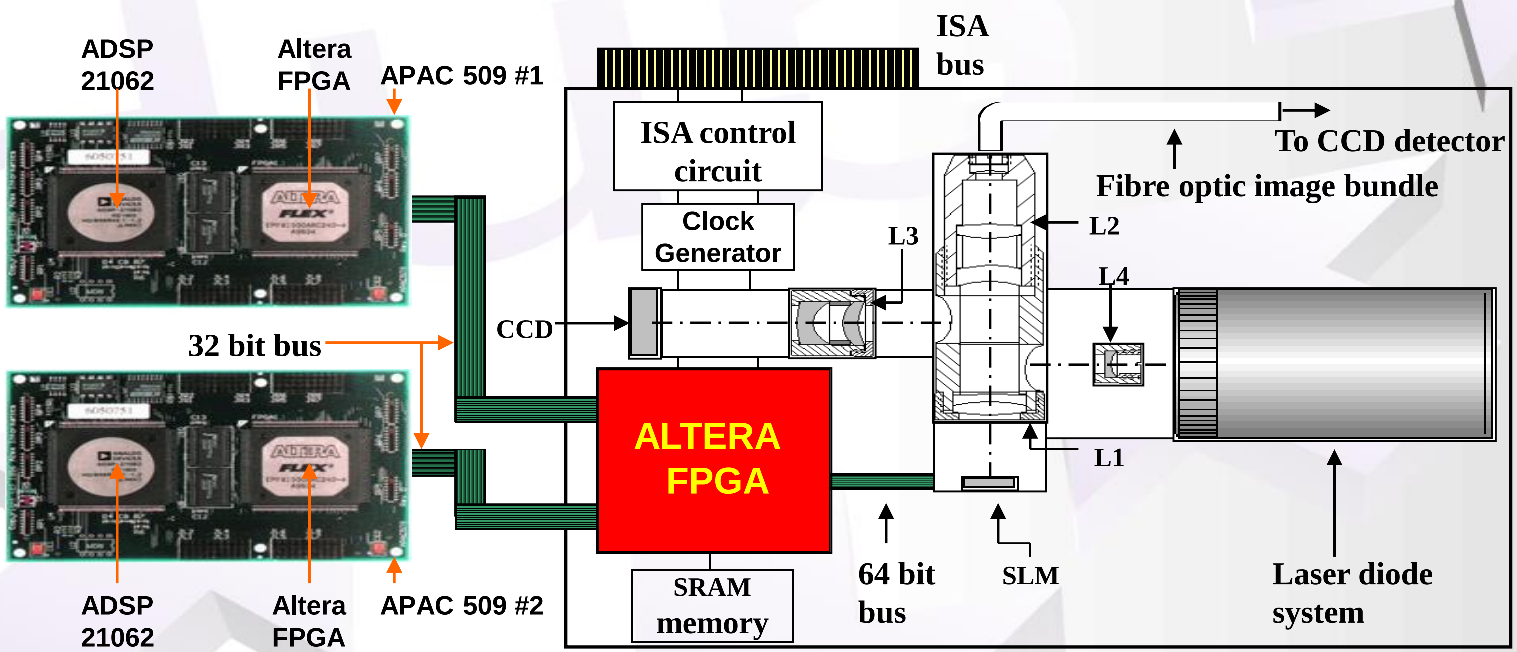


Timing Performance of 2D FFT (*ms*) for 1 group of 4 DSP

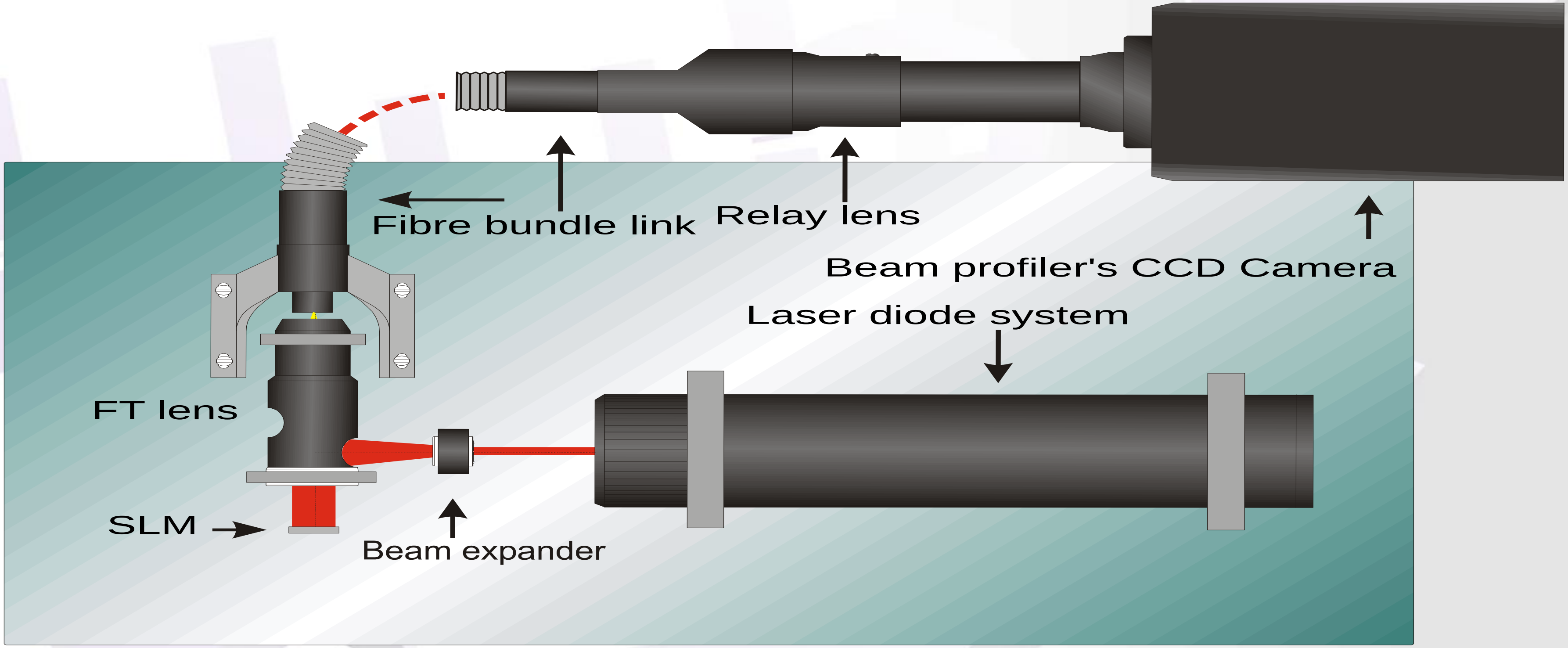
Stages	***Transpose and float***	***1st-pass FFT***	***Data re-ordering***	***DSP Communication***	***Re-order & group***	***2nd-pass FFT***	***Packing***	***Total elapsed***
Time(ms)	***3.45***	***26.40***	***3.30***	***14.20***	***3.52***	***17.10***	***7.40***	***75.37***

Image Processing & Photonics

Custom Hybrid Optical/Digital PC Card Layout



Optical Layout



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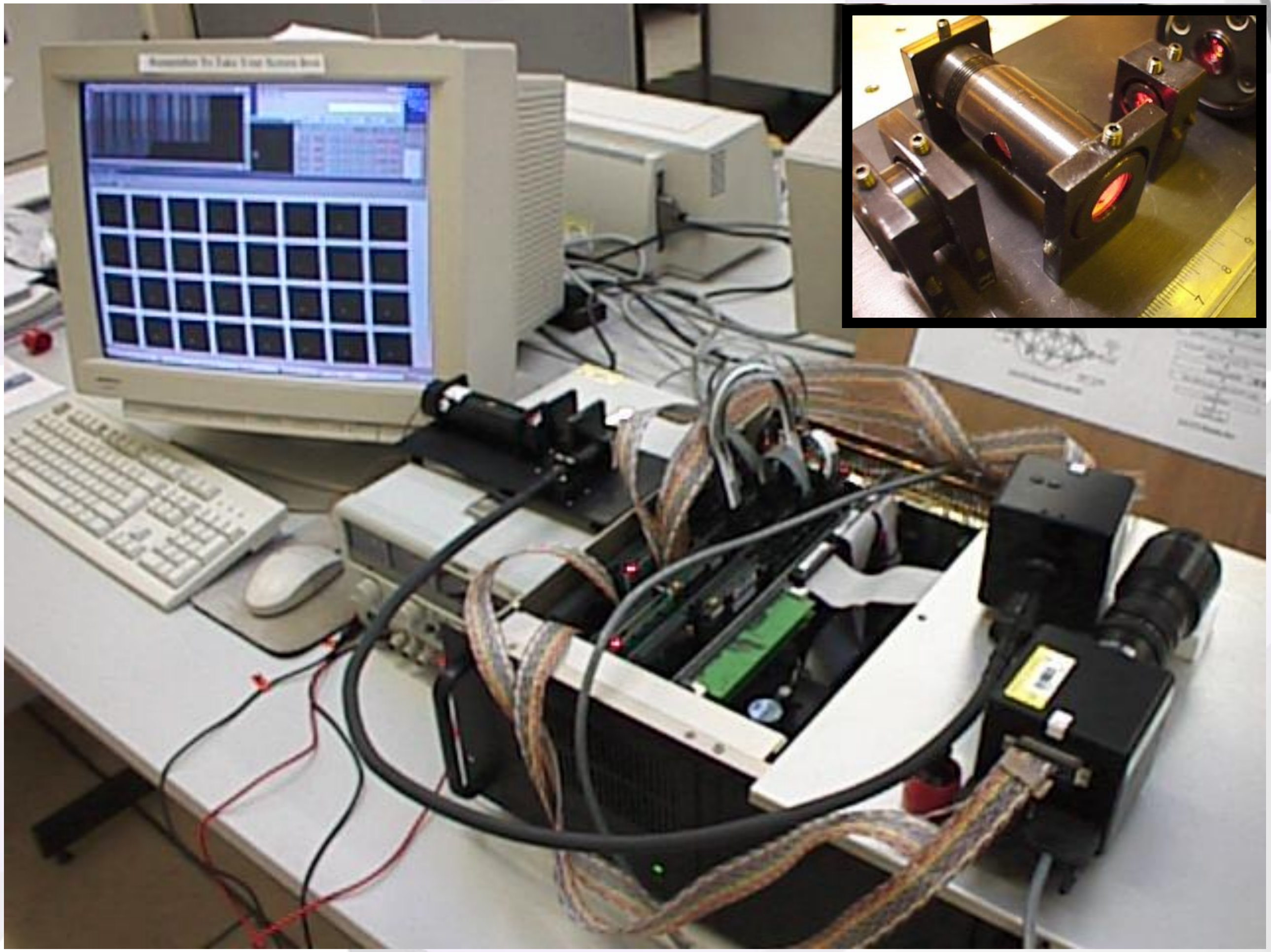
Hybrid digital optical correlator system



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PCI Bus Hybrid System

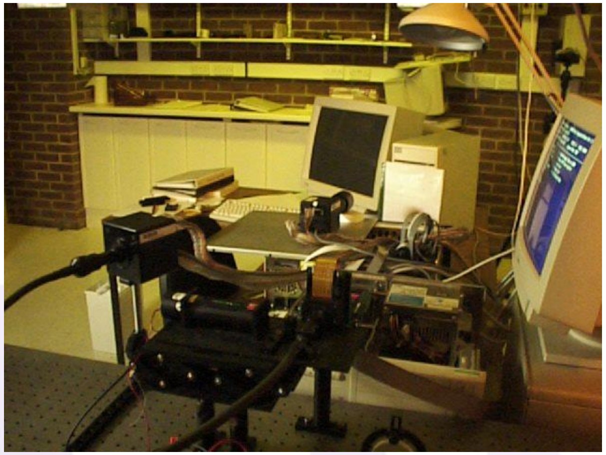
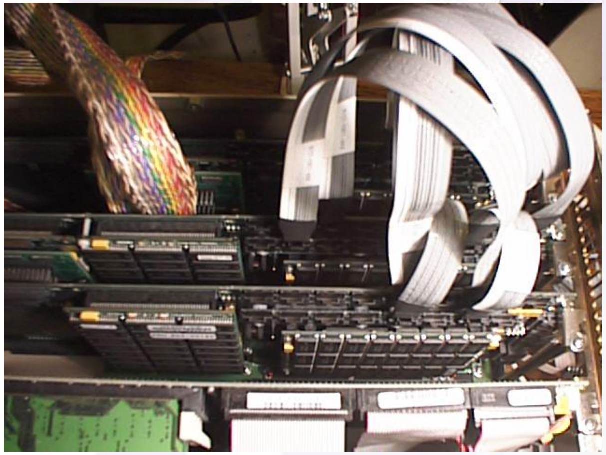
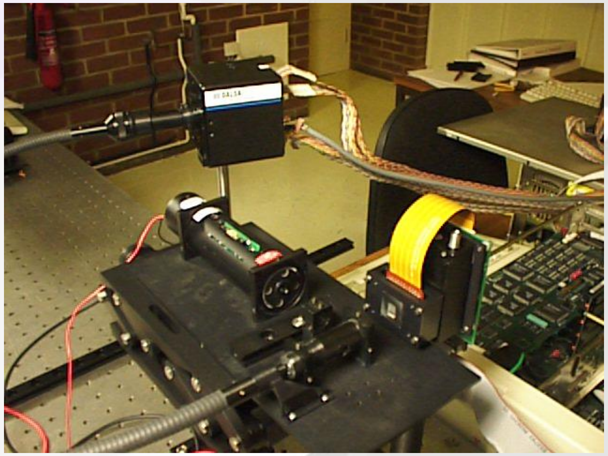
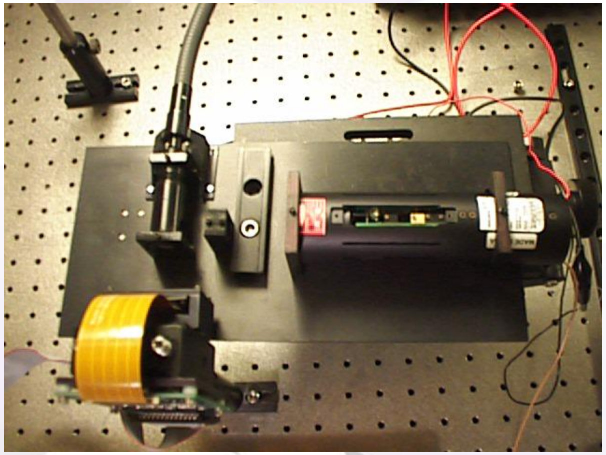
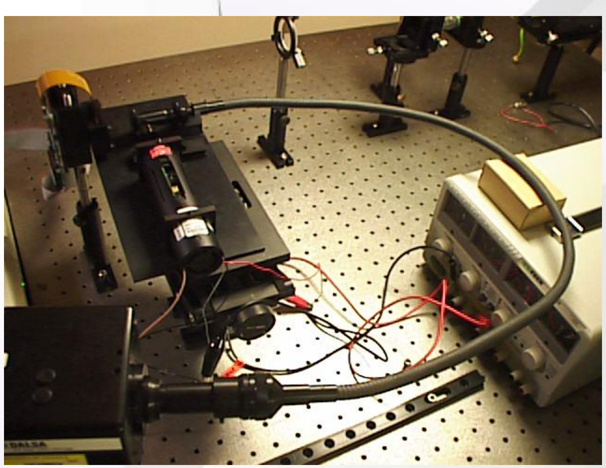

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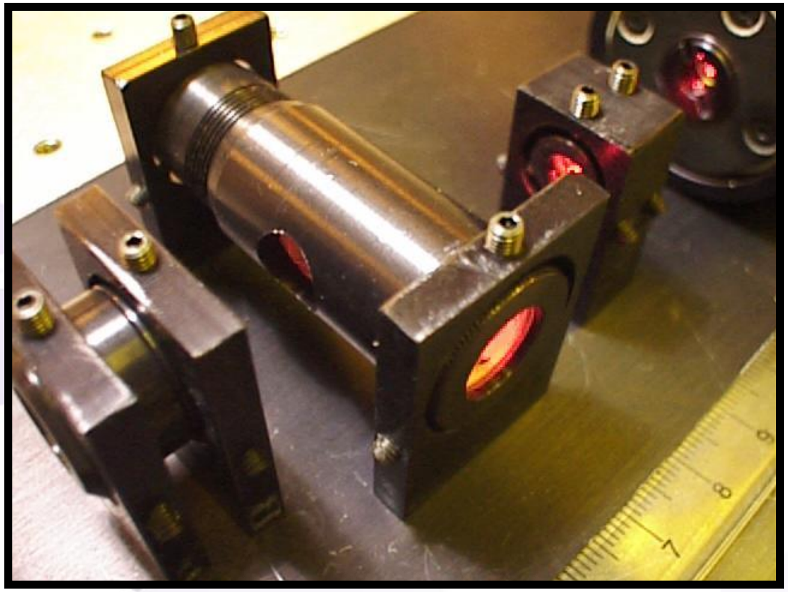
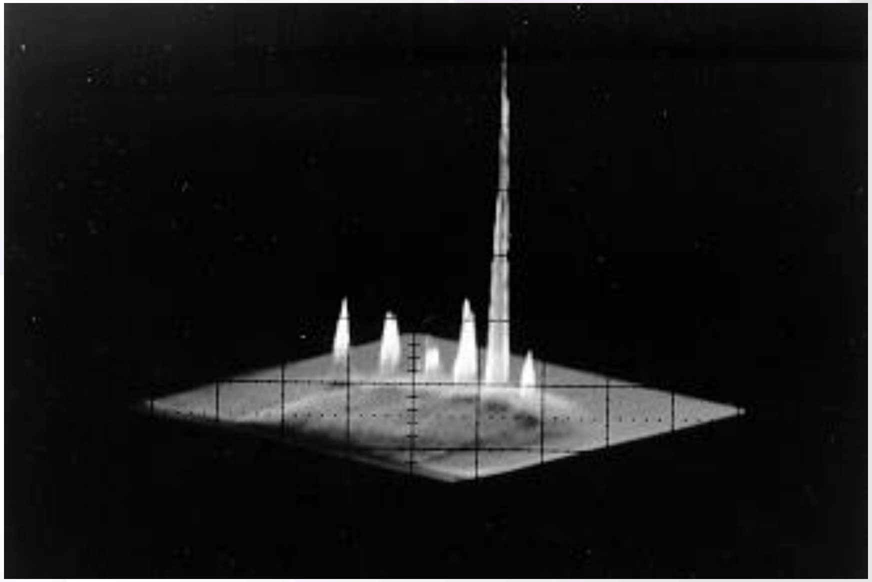
Image Processing & Photonics





Miniaturised Optical Computer, plugs into PC bus

Output Correlation

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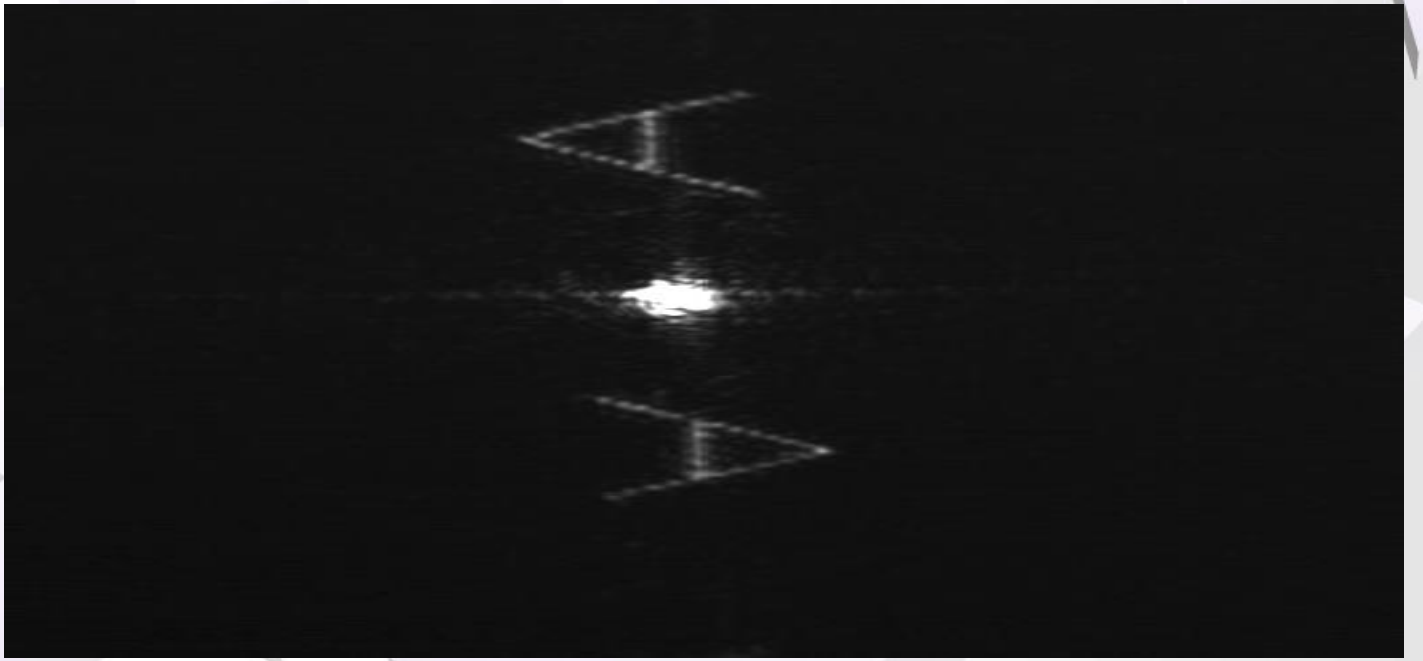
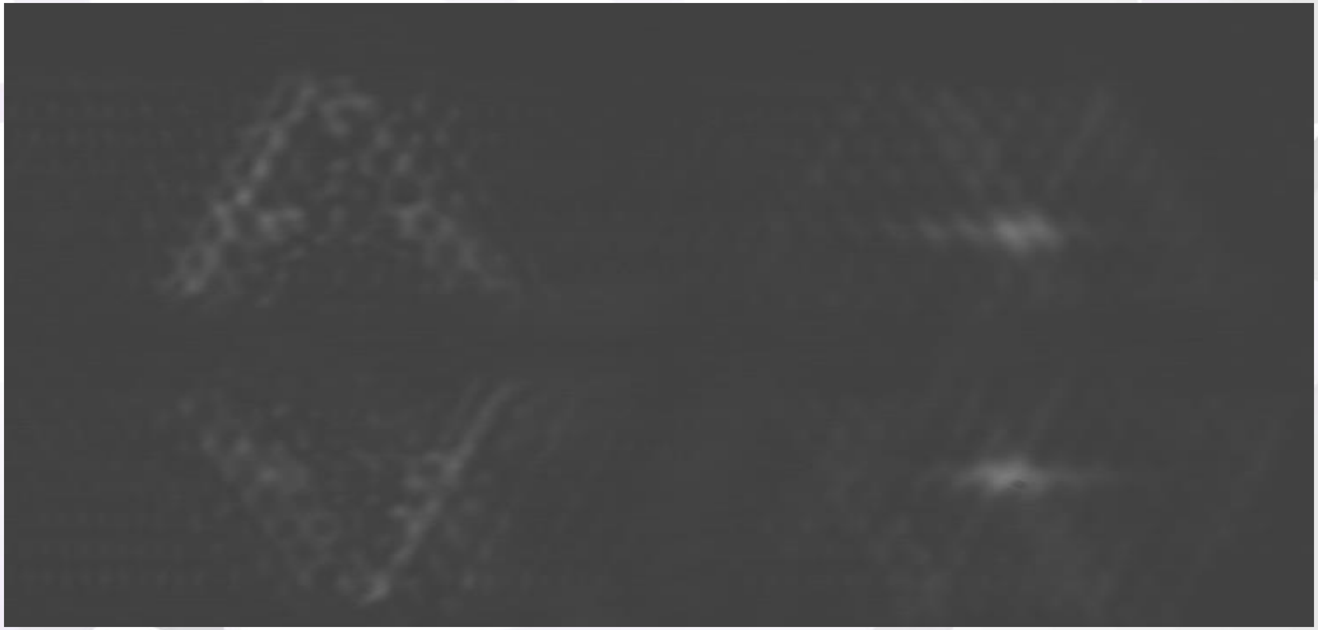
Complex Modulation Method with AFLC: Results



Example Correlation Result for Real Only Filter



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Example Correlation Results for Fully Complex Filter

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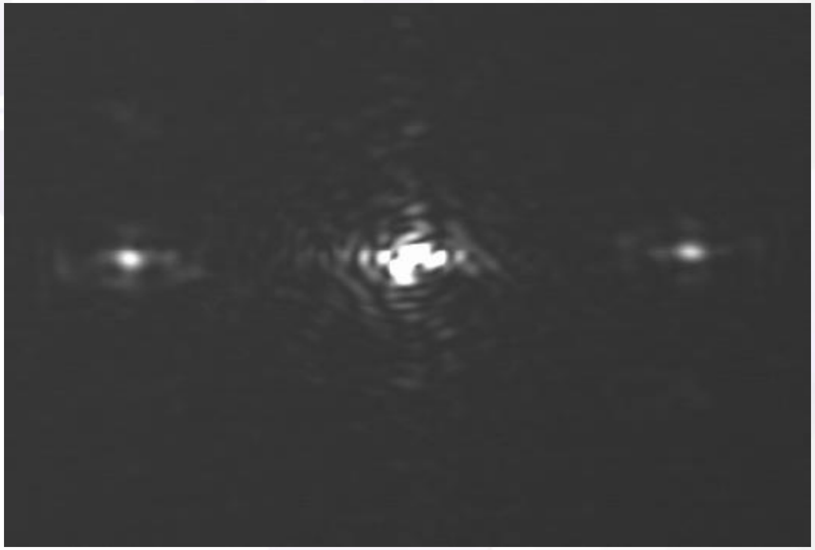
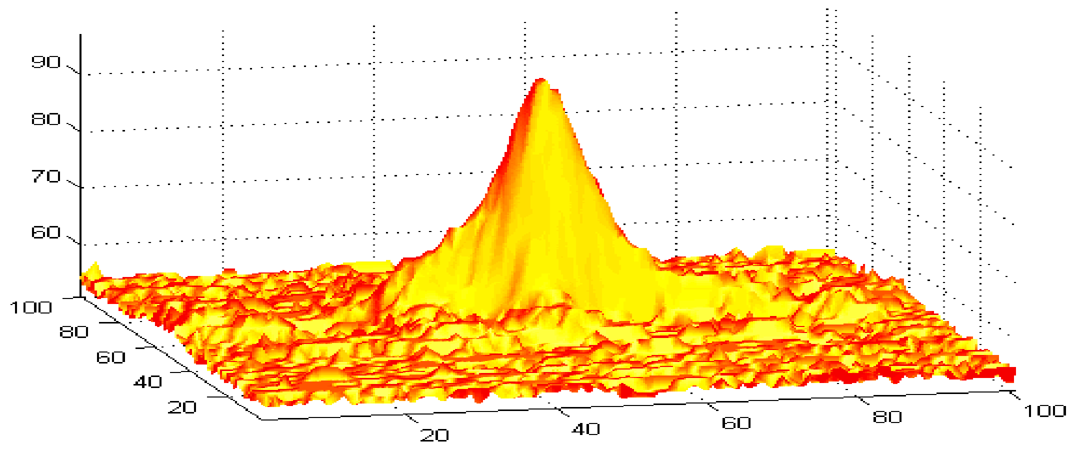
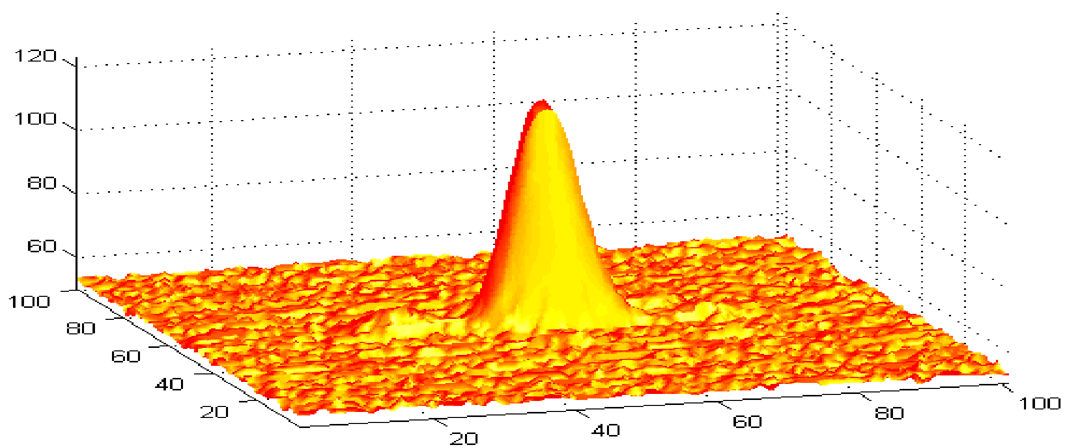
Hybrid Correlation Result



Fully Complex Hybrid Correlation

Matched filter





Phase only filter

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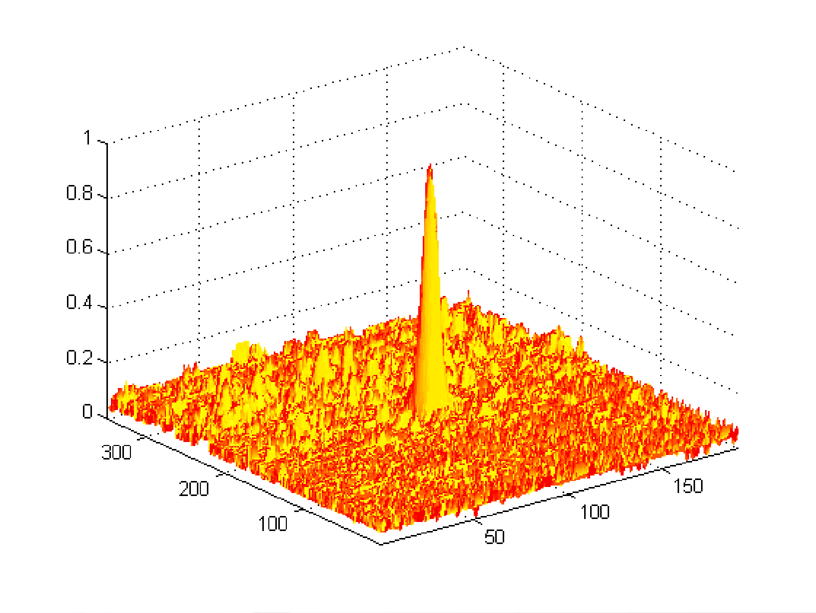
Wiener Filter Example



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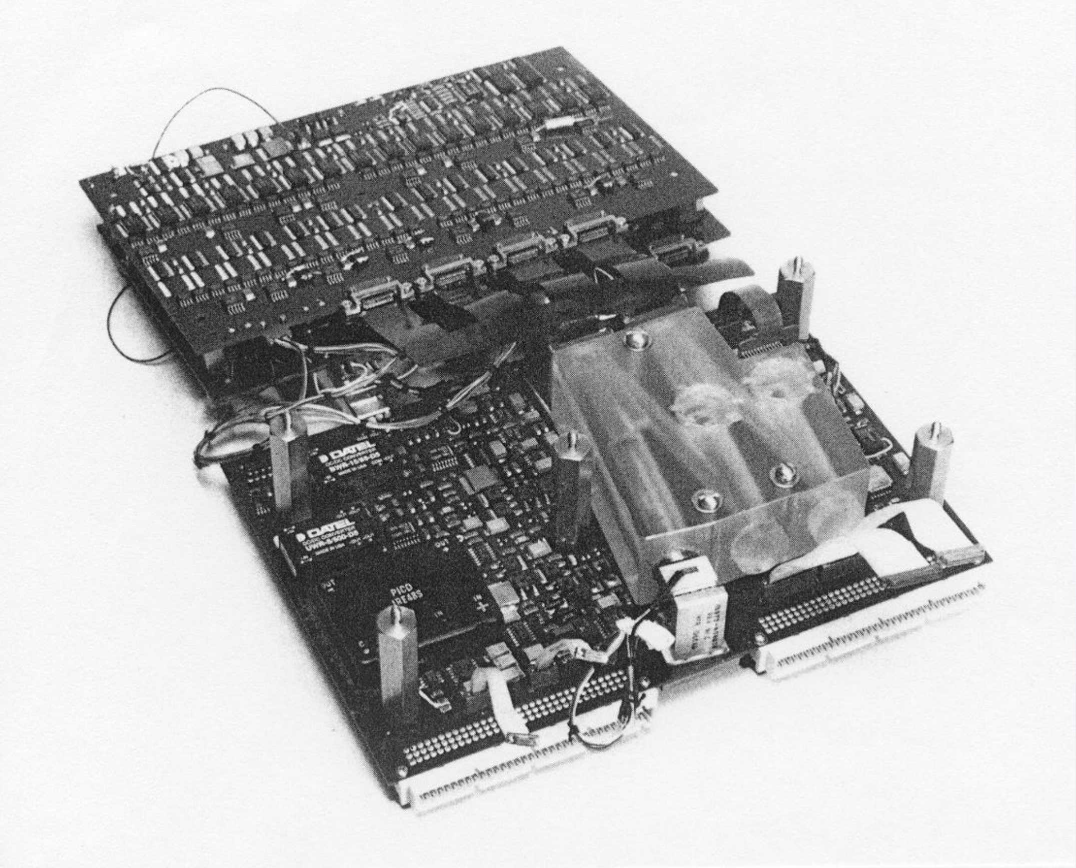
Litton Hybrid Correlator



Litton Data Systems MROC™ Optical Correlator System

Conclusions

- Complex modulation technique demonstrated using two pixels of an SLM
- All optical demonstration
- Hybrid digital/optical system over comes some problems with all optical correlators
- Future in DSP : ADSP 21160

  100 MHz, 700 Mbytes/s, 600 MFLOPS

  1024 pts CFFT in 90us (540us for 21060)

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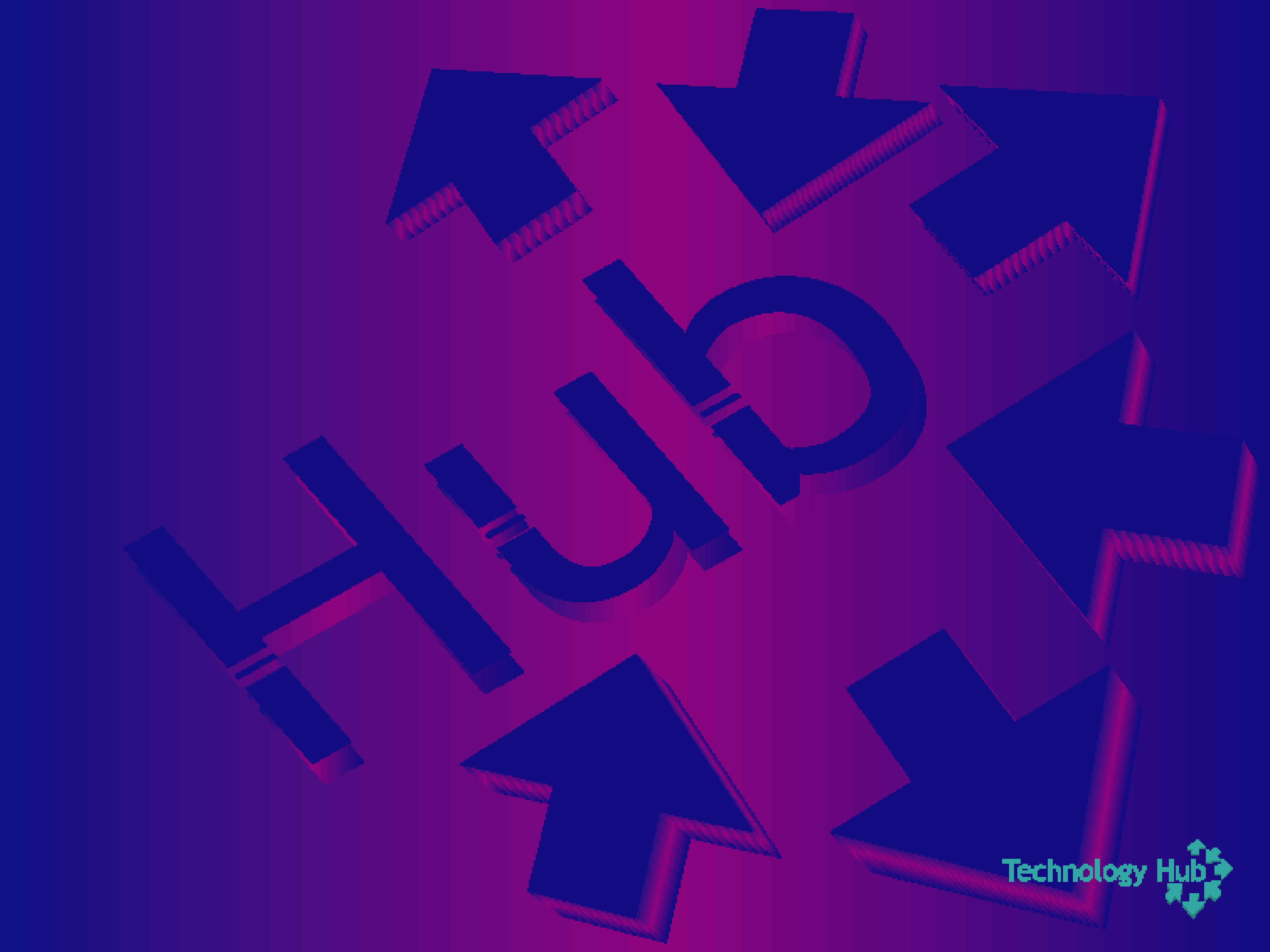
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